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Financial analysis of agrivoltaic sheep: Breeding and auction lamb business models

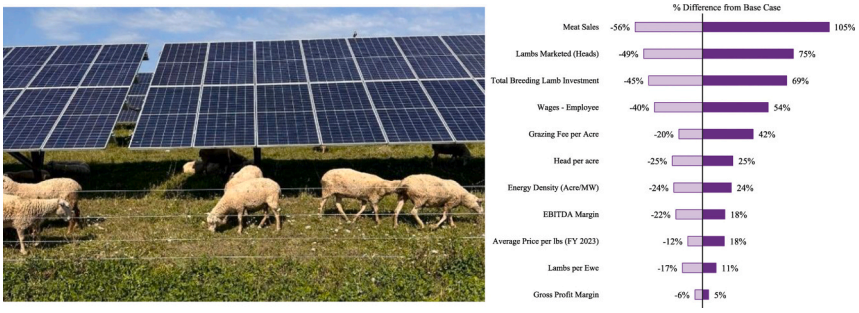
Adam Gasch [a,b], Rafael Lara [c], Joshua M. Pearce [b,d,*]

[a] Integrated Engineering, Western University, ON, Canada
[b] Ivey School of Business, Western University, ON, Canada
[c] The Lara Costa, Vittoria, ON, Canada
[d] Department of Electrical & Computer Engineering, Western University, ON, Canada

HIGHLIGHTS

- Agrivoltaics: Solving land-use conflicts with dual-purpose solar farms.
- Enhanced productivity: Improved EBITDA margins and competitive ROI.
- Environmental benefits: Optimal land use efficiency and reduced emissions.
- Economic potential: Canada's sheep supply can drive exports and rural growth.
- Scalability: Agrivoltaics offer long-term profitability amidst market fluctuations.

GRAPHICAL ABSTRACT



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ABSTRACT

Controlling vegetation on photovoltaic (PV) farms with sheep grazing is a mature form of agrivoltaics with massive potential to accelerate growth in the sheep farming industry. Agrivoltaic systems are environmentally superior to conventional PV systems, but sheep grazing business models have not been explored in detail. Thus, this study assesses profitability of agrivoltaic sheep grazing and lamb husbandry business models using case studies at two scales (200 kW to 465 MW) for breeding ewes for lambs on the farm and purchasing lambs from auction. For each model, revenue streams, costs and investments are investigated using sensitivity analyses. The results show that despite differences in operational approaches, both base cases, earnings before interest, tax, depreciation and amortization (EBITDA) margins are higher than agriculture industry values due to the increased and reliable revenue source of grazing services. Return on investments (ROIs) for the breeding model range for 16–31 % and the auction model 22–43 % for identical scenarios. While the breeding model exhibits higher EBITDA margins, the auction model offers greater ROI potential, reflecting trade-offs between operational efficiency and initial investments. The results clarify the resilience of agrivoltaics to economic fluctuations, while highlighting sheep agrivoltaics as a stable and profitable investment.

* Corresponding author at: Ivey School of Business, Western University, ON, Canada.
E-mail addresses: agasch@uwo.ca (A. Gasch), rafael@thelaracosta.com (R. Lara), joshua.pearce@uwo.ca (J.M. Pearce).

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Nomenclature

CAGR	compound annual growth rate
D&A	depreciation and amortization
EBITDA	earnings before interest, tax, depreciation and amortization
PV	photovoltaic
ROI	return on investment
ROIC	return on invested capital
UFCF	unlevered free cash flow

1. Introduction

The fastest growing energy source is solar photovoltaic (PV) [1,2], which is fortunate as it is also the most promising energy source to obtain a sustainable state [3]. To provide for all global society's energy needs with PV, however, it is believed to demand large surface areas for utility-scale solar farms [4]. These land demands for PV can develop into land use conflicts between energy generation and food production [5–8]. This conflict is exacerbated by the world population growth rate of 2.7 % per annum [9]. Human population growth to 9.1 billion people by 2050 is expected to increase food production demand by 70 % between 2005 and 2050 [10]. Last time there was a serious land use conflict between energy (ethanol) and food, costs increased along with world hunger [11–13]. One way to overcome this challenge is to use the UN's [14] 2, 8, 12 and 13, which encourages innovative and synergistic uses of land, which in this context is the co-location of agriculture and PV: agrivoltaics [15,16].

Agrivoltaics has incredible potential to provide vast quantities of sustainable electricity. In Canada, less than 1 % of farmland could eliminate the need for fossil fuel electricity [17], while in the U.S., less than 1 % farmland is required for agrivoltaics to meet 20 % of U.S. electric generation [18]. As agrivoltaics is an economically lucrative method [19] to increase land use efficiency [20,21], it has been growing quickly at a projected CAGR of 10.1 % between 2022 and 2031 [22]. Agrivoltaics is thus a technically viable solution to the PV industry's land use conflicts [23]. The disadvantages of agrivoltaics primarily encompass the additional business complexity of the site and thus the clarity of the economics.

Agrivoltaics, was first widely popularized for raising animals such as lamb [24] and sheep [25–27], emu [28], rabbits [29,30] and fish in aquavoltaics [31–33]. Sheep agrivoltaics are by far the most popular type of animal-based agrivoltaics, as not only do shepherds [34] generally support the concept, but so does the solar PV industry [35] as they both garner logistical benefits. The PV owners obtain weed control in a safe means (e.g. avoids herbicides and mowing that can kick up stones and break modules) and the shepherd obtains grazing area for the sheep. In a key study, Andrew et al. determined that although solar pastures decrease herbage 38 % lower than conventional unshaded open pastures due to full shading beneath the solar farm PV modules, this was offset by higher forage quality, resulting in similar spring lamb production to open pastures (2021a). Other studies have seen increases in pasture yield [36], that means even more revenue per acre [37]. Land productivity can thus be greatly increased because sheep grazing is at least constant (if not higher) while substantially more value is generated by land with the PV-generated electricity [38]. PV systems benefit the animals by offering shading that they prefer [39]. There is also some evidence that this approach helps improve public perceptions of PV systems as agrivoltaics retain the agricultural features of the landscape even with large solar farms [40,41]. The American Solar Grazing Association exists to promote grazing sheep with PV (2021), and it is now widespread throughout the U.S. and Canada [42]. Finally, sheep-based agrivoltaics is extremely green as shown by a life cycle analysis as it is twice as land use efficient as providing sheep and PV services separately [43]. In addition, it has 3.9 % better global warming potential than conventional PV and sheep grazing separately and is 280 %–894 % better than conventional grids in the U.S. and sheep production [43]. In North American there is a substantial opportunity to expand sheep-based agrivoltaics even if the continental sheep herd is not expanded. For example, if the current 5.2 million sheep in the U.S. were applied to agrivoltaic systems, the U.S. would need to expand utility scale PV by 400 % [43]. In Canada, there are 827,200 sheep and lamb on farms [44]. Yet, over 28,380 t of mutton and lamb are imported from countries like Australia and New Zealand (Wood, 2018), compared to 16,630 t of mutton and lamb produced locally [44]. Agrivoltaics as an emerging innovation in solar technology has massive potential to spur growth in the Canadian sheep farming industry. A sheep grazing business model, however, has not been explored in detail. There is evidence that agrivoltaic systems are superior to conventional photovoltaic systems environmentally, but an economic case is required in order to make a clear financial motivation to pursue this approach to scale.

To fill that knowledge gap, this study will assess the profitability of agrivoltaic sheep grazing and lamb husbandry to understand its feasibility for adoption on solar farms. It should be noted that no changes to the conventional solar farm design are necessary to introduce sheep grazing and there is no change in energy yield for introducing sheep. Two business model methodologies will be considered: 1) breeding ewes for lambs on the farm and 2) purchasing lambs from the auction. A case study in Ontario, Canada is used to illustrate the potential of this method. Since solar projects in Canada can range in size from 200 kW [45] to as large as 465 MW [46], each business model is analyzed to reflect the range of PV site scales. For each model, revenue streams, costs and investments will be investigated using a sensitivity analysis over variables to understand high, base, and low case profitability outcomes. Furthermore, sensitivities are run for key drivers of profitability such as lamb prices, heads per acre, lambs per ewe, and lamb growth per day to examine effects on each business model. The results are reviewed in the context of current Canadian sheep farm profitability and renewable energy investment projects to gauge if this has the potential to be an attractive investment opportunity for farmers, investors, and government bodies.

2. Methods

Lambs grazing under solar panels are shown in detail in Fig. 1 and an ariel view of one of the largest PV farms in Ontario to illustrate the scale of such operations in Fig. 2. To understand the economics of both the breeding and auction business models at various scales, as shown in



Fig. 1. Lambs grazing on solar farm in southern Ontario.



Fig. 2. Areal view of lamb grazing on 130 MW solar farm.

Table 1
Canadian solar farm scale range.

Scale	Energy Capacity (MW)	Solar Farm Size (acres)	Source
Largest Farm	465	2093–3395	[46]
Utility Scale	50	225–365	[45]
Average Scale	11	50–80	[47]
Community Scale	0.2	1–1.5	[45]

Table 1, a financial profitability model was created to determine top line revenue streams with associated costs of sales to determine gross profitability, as well as operating expenses to determine earnings before interest, tax, depreciation and amortization (EBITDA) and EBITDA margin. For each scale of PV farm, the acres used will vary based on power density which ranges from 4.5 acres per MW for fixed-tilt, conventional PV systems [48], (which is as close packed as possible without major shading losses) to a weighted average capacity of 7.3 acre per MW for direct land-use requirements [49] such as for more purposeful spaced out agrivoltaics. It should be noted that sheep-based agrivoltaics is appropriate at both monofacial and bifacial PV farms. The latter is advantageous as there is both an increase in yield (10–30 %) from bifacial systems [50–52] as well as decreases in snow losses due to faster panel clearing with bifacial systems [53–55].

2.1. Revenue

Sources of revenue common to both business models consist of the sale of lamb meat and grazing services provided for PV farms, which earn a median rate of US$194[1] per acre per year [56]. To determine meat sales, the number of marketed lambs needed to be calculated. First, for either business model, the flock size can be determined based on stocking densities of six to ten sheep per acre, which will vary according to climate, topography and grass quality [57]. The number of marketed lambs will differ for each model since a portion of the flock are ewes in the breeding model, compared to the auction which are all lamb.

For the breeding model, a percentage of the total flock size was dedicated to an initial stock of ewes for breeding and reproduction [58]. Each ewe gives birth to 1.5 to 2 lambs [59–61] and for flock sizes greater than 750 ewes, 96 % become pregnant [62]. Therefore, using the number of lambs per ewe and the pasture's flock capacity, the initial stock of ewes was calculated. From this and ewe pregnancy rates, the number of lambs born in the lambing season and total flock size was determined. A percentage of ewe lambs born are kept for breeding in the next season, and this percentage will variate depending on the producer's goal and strategy for genetic improvement [63]. For example, if the heaviest ewe lambs are selected, this represents roughly 30 % of the ewe lamb flock, however, if the heaviest and most worm resistant were selected, this would be lower than 30 %. For this consideration, the percentage of ewe lambs retained for breeding in the next season can range from 22 % to 40 % [64]. Since the sex ratio of lambs is 49.8 % female and 50.2 % male [65], this means that 11 % to 20 % of the lambs born are kept for breeding and reproduction. Any ewes that did not become pregnant in the lambing process can be marketed and sold as another source of revenue for this business model. They can be sold at either sheep or lamb prices depending on their age and size [66]. The initial birth weight of each lamb can vary but is assumed to be normally distributed [67]. Their sale price will depend on their final weight and time of year sold [66]. Furthermore, ewes are typically sheared once per year [68], and the wool can then be sold for some additional revenue [69].

Table 2
Revenue input assumptions.

Item	Value	Unit	Source
Grazing Fee	212–374	CAD$/Acre	[56]
Stocking Density	6–10	Heads/Acre	[57]
Grazing Season	150	Days	[71]
Lamb Growth[1]	80–110	g/day	[70]
Lamb Birth Rate	1.5–2	Lambs/Ewe	[60]
Ewe Pregnancy Rate	96–100	%	[62]
Lamb Sex Ratio	49.8	%	[65]
Replacement Ewe Benchmark	20–40	%	[64]
Lambs Birth Weight	Normal Distribution		[67]
Avg. Price of Lambs (2023)	2.13–2.86	$/lbs	[66]
Avg. Price of Lambs (Nov. to Feb. 2023)	2.42–2.67	$/lbs	[66]
Fleece Weight	6.15	Lbs/fleece	[72]
Wool Price	0.1–0.7	$/lbs	[69]

[1] 1 g = 0.002205 lb. [73].

For the auction model, the revenue sources differ as there is no initial stock of ewes, therefore the entire flock will be marketed and sold. For the auction model, a key variable is the amount of weight each lamb gains during the pasture season. This value ranges between 0.18 and 0.24 pounds per day for lamb held for longer than six weeks [70]. The length of the pasture season is typically 150 days [71]. The lamb sale price will depend on their final weight and time of year sold [66]. (See Table 2)

2.2. Costs of production

The breeding and auction business models share similar costs associated with pasture maintenance including crop insurance [74], chemical herbicides [75], and any other cost of sales [60]. The business models, however, differ in terms of the costs associated with the production of each sale.

For the breeding model, mature ewes need stored feed for the months after the pasture season [60]. This cost would not be incurred in the auction model. Furthermore, ewes need to be sheared once per year [68] which represents an additional cost of production for the breeding model [72].

The most significant cost for the auction model is the purchase price of lambs at the auction. Prices vary depending on time of year and weight of lamb [76]. Lambs are typically purchased at weights below 30 to 35 kg[2] [70]. (See Table 3)

[1] All currencies will be in Canadian dollars at an exchange rate of $1.3585 CAD to USD (Google Finance, 2024)

[2] 1 kg = 2.205 lb. [73]

Table 3
Cost of sales input assumptions.

Item	Value	Unit	Source
Mature Ewe Feed Cost	45.43	$/Ewe	[60]
Price of Lambs (Jun. to Sep. 2023)	2.51–2.84	$/lbs	[66]
Shearing Costs	5.00	US$/Ewe	[72]
Insurance - Crop	12.05	$/Acre	[74]
Chemicals - Herbicide	1.69	$/Head	[75]
Other Cost of Sales	3.62	$/Acre	[60]

2.3. Operating expenses

The breeding and auction business models will share similar operating expense structures between equipment repairs [77], animal health costs [60], building and land (fence) repairs [60], fuel and oil [77], and miscellaneous expenses such as office expenses, small tools, and supplies [78]. A key expense, however, such as direct labour costs will vary based on the business model and scale of the operation. The operation can be lean since only six hours of labour is required per head per year during spring lambing and winter feeding [79]. At large scales, the operation would also need a manager to determine breeding strategies, establish a marketing program, organize rotational pasture activities, scheduling of resources, and hire personnel [80]. A farm manager in Ontario earns an average salary of $78,092 [81]. For most operations, the manager would also perform farming duties and can be counted as part of the total number of herders [80]. During the pasture season, herders work at least 60 h per week [82].

For the breeding model, however, less labour hours are required in the winter since there is more work to do during the pasture season due to the larger flock size [83]. In the auction model, there will be less overall direct labour costs since operations are only conducted during the pasture season. Foreign workers are typically hired for work on Canadian agriculture farms due to domestic labour shortages (Government of [84]). These workers in Ontario earn a rate of $16.71 per hour [85]. Other expenses that differ between the two operations are veterinary pregnancy diagnosis [86], and marketing and transportation [77]. Since the auction model does not have pregnant ewes, the cost of checking for pregnancy will not be incurred compared to the breeding model. Marketing and transportation will vary based on the number of heads sold at the auction and would therefore be much larger for the auction model due to a higher number of heads sold per year. Operating insurance can also be expensed to protect the operation against downside market prices and is also charged on a per marketed head basis [78].

To assess the attractiveness each business model and scale of operations, EBITDA margins can be compared to agricultural production and renewable energy services industry results. EBITDA margin will be used since interest, tax, depreciation and amortization can very depending on financing used, and investments made. This will provide a fair comparison on each business models ability to generate cash. For the agriculture production industry the annual EBITDA margin as of the fourth quarter of 2023 earned 7.32 % [87], while the renewable energy services and equipment industry earned 17.44 % over the same period [88]. Therefore, EBITDA margins above these figures can be considered efficient in generating cash compared to industry peers. (See Table 4)

2.4. Capital costs

A lamb grazing operation requires the investment of fencing, vehicles, water systems, mineral feeders, mobile corral, and dogs [63] as listed in Table 5. The quantity of each investment will vary depending on flock size, scale of operation, and number of paddocks for the rotational grazing pasture. The breeding and auction models would require the same initial investments, except the breeding model requires an initial stock of ewes that the auction model would not.

To understand each business model's return on investment (ROI), taxes payable and unlevered free cash flow (UFCF) were calculated. To derive taxes, depreciation and amortization (D&A) for each initial investment was determined using the straight-line method with the useful life of each asset from Table 6. Utilizing the EBITDA generated from the profitability analysis, D&A was subtracted to obtain EBIT. This value was then multiplied by the alternative minimum tax rate for farming operations of 15 % to 20.5 % for farming operations [92]. Subtracting tax from EBIT and adding back D&A then yielded the UFCF. To calculate ROI, UFCF was divided by initial investment. To understand the attractiveness of this investment opportunity, ROI can be compared to agricultural production and renewable energy services industry results. For the agriculture production industry the annual ROI as of the fourth quarter of 2023 earned 12.36 % [93], while the renewable energy services and equipment industry earned 2.18 % over the same period [94].

To understand how free cash flow of the operation would be impacted if debt were used to fund the initial capital investments, further analysis was conducted. The term of debt was assumed to be 10 years, and interest was calculated at the current average business loan rate in Canada of 7.06 % [95]. Although debt decreases the amount of free cash flow due to annual interest expenses and principal repayments, it also provides tax shielding benefits and higher equity returns at the end of the repayment period. The tax shield was calculated by recalculating tax to include the interest expense and comparing tax in the unlevered and levered case scenarios and the return on invested capital (ROIC) was calculated by dividing the levered free cash flow by the capital used to finance the initial investment. (See Table 5)

Table 4
Operating expenses input assumptions.

Item	Value	Unit	Source
Equipment Repairs	7.15	$/Ewe	[77]
Worker Capacity	6	Hours/head/year	[79]
Pasture Season Hours	12	Hours/day	[82]
Rate per Hour	16.71	$/Hour	[85]
# of Managers	1	Manager	[80]
Manager Salary	78,092	$/Year	[81]
Ewe Veterinary Fees - Pregnancy	2.40	US$/Ewe	[86]
Animal Health Costs	3.11	$/Ewe	[60]
Building & Land (Fence) Repairs	4.58	$/Ewe	[60]
Fuel & Oil	6.69	$/Ewe	[77]
Trucking	5.50	$/Marketed Lamb	[77]
Commission, Fees, etc.	6.55	$/Marketed Lamb	[77]
Insurance - Operating	1.64	$/Marketed Lamb	[78]
Miscellaneous	1.00	$/Ewe	[78]

Table 5
Capital investment input costs.

Item	Value	Unit	Source
Breeding Stock	1.36–1.87	$/lb	[66]
Fencing:			
T Posts	10.98	$/Post	[96]
Portable White Posts	3.98	$/Post	[97]
Reels	176.99	$/Reel	[98]
Wire	172.99	$/Bundle	[99]
Energizer	377.99–4005.99	$/Energizer	[100]
Vehicles:			
Heavy Duty Truck	30,000–120,000	$/Truck	[101]
Light Vehicle	40,000–60,000	$/Vehicle	[102]
Water System:			
Troughs	232.15	$/Trough	[103]
Moveable Water Tank	5143	$/Tank	[104]
Large Tank	1937.28	$/Tank	[105]
Mineral Feeder	279.95	$/Feeder	[106]
Mobile Corral:			
Gates & Corral	50,000–60,000	$/Corral	[107]
Scale & Computer System	10,000	$/Scale	[108]
Dogs	600–1200	$/Dog	[109]

Table 6
Useful life of assets.

Capital Investment	Useful Life	Source
Breeding Stock	5 years	[89]
Fencing	15 years	[90]
Vehicles	5 years	[90]
Water System	10 years	[90]
Mineral Feeder	7 years	[90]
Mobile Corral	10 years	[90]
Dogs	8 years	[91]

2.5. Sensitivity

For inputs that have a range of values, a high-low sensitivity analysis will be conducted to understand what the potential range of values could be in the financial analysis. The best assumptions will be used for the high case such as highest possible revenues at lowest possible costs, and the worst assumptions will be used for the low case such as lowest possible revenues at lowest possible costs. The base case will be the average or most common value that falls between the high and low cases to provide a more realistic figure for what a farmer can expect.

Further sensitivity will be conducted on these inputs that have a range of values to provide the full perspective of how inputs affect EBITDA margin or other key metrics. These sensitivity analyses will be conducted using data tables and heat map visualizations.

3. Results

3.1. Profitability analysis

Following the methods for the profitability analysis, Table 7 and Table 8 demonstrate the EBITDA associated with the breeding and auction business models, respectively for a utility scale operation. The results also include high and low case sensitivities around key variables such as grazing service fees, heads per acre, lamb growth per day, input costs, wages, and other operating costs. The key differences in these business models pertain to meat sales, cost of sales and operating expenses.

When analyzing the base case for the utility scale business models, for the breeding model in Table 7, there are 54 % less meat sales compared to the auction model in Table 8. This is due to the key difference in operating model of retaining 48 % of the flock for breeding and reproduction in the next season. The auction model, however, has an 8× higher cost of sales since the operating model dictates that the flock of lambs are to be purchased from the auction, rather than born on the farm. This accounts for the 49 % higher gross profit margin in the breeding model compared to the auction.

In terms of operating expenses between the base case for the utility scale business models, the breeding model has 1.3× higher expenses than the auction model. This can be attributed to higher direct labour costs due to labour being employed year-round compared to the auction model which hires labour seasonally only during the 5-month pasture season. Furthermore, the breeding model incurs the cost of veterinary pregnancy checks which the auction model does not. The breeding model, however, requires less marketing and transportation costs due to 52 % less lambs being marketed and sold at the auction.

Overall, the breeding model earns an 11 % higher EBITDA margin than the auction model due to reduced input costs associated with the cost of purchasing lambs at the auction. In both base cases, EBITDA margins yield a higher return than the agriculture industry trend of 7.32 % due to the increased and reliable revenue source of grazing services. The high case for each business model yielded a 40 % and 22 % EBITDA margin for the breeding and auction models, respectively. These figures are greater than the 17.44 % EBITDA margins earned in the renewable energy services and equipment industry. Therefore, since the high scenario can compete with renewable energy services, and the base scenario against other agriculture production, both business models can be viewed as an attractive solution to generate cash flows for sheep farmers. Furthermore, the low case scenarios for each business model do not represent significant concerns for farmers. In the breeding model, the low case breaks even at 0 % EBITDA margin, while the auction model reaches −4 %. For the auction model, this loss does not pose a great concern since the projection sold lambs at the auction for prices below what the lambs were purchased for. This would not represent the usual operating performance but can provide farmers with assurance that if this were the case, losses would be mitigated to −4 %.

Table 9 summarizes the overall EBITDA margin of each operation to understand the potential returns or losses of each operating model and scale of operation based on the profitability analysis conducted. A key insight generated from analyzing each scale is the nature of expenses incurred in each business model. Each scale generates roughly the same EBITDA margins for each case. This is due to the costs being incurred as variable and are dependent on either the number of heads in the flock, or the size in acres of each farm. There were no high fixed costs identified in these operations which is favourable for farmers since the operation starts at a breakeven volume.

Table 7
Breeding profitability model (Fiscal Year End April 30).

Item	High	Base	Low
Scale		*Utility Scale*	
Sales:			
Grazing Services	$136,510	$77,833	$47,736
Solar Capacity (Acres)	365.00	295.00	225.00
Meat Sales	567,963	277,523	122,971
Number of Ewes (Heads)	1217	843	540
Number of Lambs Born (Heads)	2433	1456	794
Total Flock Size (Heads)	3650	2299	1334
Number of Ewe Lambs (Heads)	1212	725	395
Replacement Ewes (Heads)	267	218	158
Lambs Marketed (Heads)	2167	1239	636
Average Price per lbs. (FY 2023)	2.86	2.43	2.13
Average Weight (lbs)	90	90	89
Number of Non-Pregnant Ewes	49	34	11
Wool Sales	6389	2610	430
Total Sales	**$710,862**	**$357,966**	**$171,137**
Sales per Acre	*1948*	*1213*	*761*
Sales per Head	*195*	*156*	*128*
Cost of Sales:			
Total Cost of Sales	**$77,247**	**$54,011**	**$35,059**
Cost of Sales per Acre	*212*	*183*	*156*
Cost of Sales per Head	*21*	*23*	*26*
Gross Profit	**$633,615**	**$303,955**	**$136,078**
Gross Profit per Acre	*1736*	*1030*	*605*
Gross Profit per Head	*174*	*129*	*101*
Gross Profit Margin	*89 %*	*85 %*	*80 %*
Operating Expenses			
Wages - Employee	$273,400	$177,367	$106,720
Direct Labour - Lambing & Pasture Season (Hours)	12,775	8048	4668
Direct Labour - Winter (Hours)	3586	2567	1718
Total Herder Wages	273,400	177,367	106,720
# of Managers	0	0	0
Ewe Veterinary Fees - Pregnancy	3971	2751	1763
Marketing & Transportation	26,109	14,928	7660
Trucking	11,917	6814	3496
Commission, Fees, etc.	14,192	8115	4164
Remaining Operating Expenses	43,464	30,309	20,154
Total Operating Expenses	**$346,945**	**$225,356**	**$136,296**
Operating Expenses per Acre	*951*	*764*	*606*
Operating Expenses per Head	*95*	*95*	*101*
EBITDA (Loss)	**$286,670**	**$78,600**	**-$219**
EBITDA per Acre	*785*	*266*	*−1*
EBITDA per Head	*79*	*33*	*0*
EBITDA Margin	*40 %*	*22 %*	*0 %*

Table 8
Auction profitability model (Fiscal Year End April 30).

Item	High	Base	Low
Scale		*Utility Scale*	
Sales:			
Grazing Services	$136,510	$77,833	$47,736
Solar Capacity (Acres)	365.00	295.00	225.00
Meat Sales	1,018,176	598,075	309,147
Total Flock Size	3650	2360	1350
Lambs Marketed	3650	2360	1350
Average Weight at Sale	104.38	99.42	94.46
Average Sale Price per Lbs (November to February)	2.67	2.55	2.42
Total Sales	**$1,154,686**	**$675,908**	**$356,883**
Sales per Acre	*3164*	*2291*	*1586*
Sales per Head	*316*	*286*	*264*
Cost of Sales:			
Lamb Costs	$622,502	$421,784	$260,819
Average Purchase Price per Lbs (June to September)	2.51	2.63	2.84
Average Weight at Purchase (Lbs)	68.00	68.00	68.00
Remaining Cost of Sales	11,888	8611	5807
Total Cost of Sales	**$634,390**	**$430,395**	**$266,626**
Cost of Sales per Acre	*1738*	*1459*	*1185*
Cost of Sales per Head	*174*	*182*	*198*
Gross Profit	**$520,296**	**$245,513**	**$90,257**
Gross Profit per Acre	*1425*	*832*	*401*
Gross Profit per Head	*143*	*104*	*67*
Gross Profit Margin	*45 %*	*36 %*	*25 %*
Operating Expenses			
Wages - Employee	$152,479	$98,589	$56,396
Direct Labour - Lambing & Pasture Season (Hours)	9125	5900	3375
Total Herder Wages	152,479	98,589	56,396
# of Managers	0	0	0
Marketing & Transportation	43,983	28,438	16,268
Trucking	20,075	12,980	7425
Commission, Fees, etc.	23,908	15,458	8843
Remaining Operating Expenses	69,804	47,680	30,188
Total Operating Expenses	**$266,266**	**$174,707**	**$102,851**
Operating Expenses per Acre	*729*	*592*	*457*
Operating Expenses per Head	*73*	*74*	*76*
EBITDA (Loss)	**$254,031**	**$70,806**	**-$12,595**
EBITDA per Acre	*696*	*240*	*−56*
EBITDA per Head	*70*	*30*	*−9*
EBITDA Margin	*22 %*	*10 %*	*−4 %*

Table 9
EBITDA margin summary.

Farm Size	Breeding			Auction		
	High	Base	Low	High	Base	Low
Largest Farm (465 MW)	*39%*	*20%*	*-3%*	*21%*	*9%*	*-6%*
Utility Scale (50 MW)	*40%*	*22%*	*0%*	*22%*	*10%*	*-4%*
Average (25 MW)	*39%*	*20%*	*-2%*	*22%*	*10%*	*-4%*
Smallest Farm (200 kW)	*38%*	*20%*	*-2%*	*22%*	*10%*	*-4%*

3.2. Sensitivity analysis

To further understand these business models, sensitivity around key drivers of financial profitability and farming operational management were conducted. The base case for the utility scale business models were analyzed to understand how the typical operation would be impacted by changes to important variables.

For the breeding lamb model, the most sensitive variable affecting financial profitability is the selling price of $2.13 to $2.76 per pound of lamb from 2023 [66]. This number will vary depending on the time of year lamb is sold, as well as the final weight of lamb. To test how this number affects profitability, Table 10 compares the average sale price against the final weight to calculate how the EBITDA margin will change. In this sensitivity, prices greater than $2 and weights over 70 lbs. will generate a positive margin. The results also suggest that this business will be very successful when prices reach $3.00 per pound or greater. Prices for lamb with a weight between 95 and 109 pounds sold for an average price of $3.18 per pound at Ontario auctions in February 2024 [66] which would yield around 35–45 % EBITDA margins for this model. Another variable that drives revenue is the grazing fee of $212 to $374 per acre. Table 11 tests how EBITDA margin changes with grazing fee and lamb prices. In this analysis, fees earned greater than $100 and prices greater than $2 will yield positive margins.

Table 10
Breeding lamb financial sensitivity – weight & price vs. EBITDA margin.

Avg. Sale Price ($/lbs) \ Avg. Weight (lbs)	70	80	90	100	110
2.00	-8%	2%	10%	17%	22%
2.25	1%	10%	17%	24%	29%
2.50	8%	17%	24%	30%	35%
2.75	14%	22%	29%	35%	40%
3.00	20%	28%	34%	40%	44%
3.25	24%	32%	38%	43%	48%
3.50	29%	36%	42%	47%	51%
3.75	33%	40%	45%	50%	54%
4.00	36%	43%	48%	53%	56%

To gain a better understanding of farming strategy around flock sizes, sensitivity was conducted on how the stocking density of six to ten head per acre and the energy density of 4.5 to 7.3 acres per MW affect the flock size. Table 12 provides farmers with insights on how they should stock their pasture for solar farms of different energy densities. This will offer adequate planning for how many heads a 50 MW PV farm can accommodate. This sensitivity would hold true for both the breeding and auction models. Furthermore, Table 13 tests how the 22 % to 40 % ewe lamb retention strategies and 1.5 to 2.0 reproduction rates affect EBITDA margins. This analysis provides farmers with how their strategy will affect EBITDA margin for the current year to offer insight on the farms ability to be more selective over the genetic makeup of their flock.

The auction lamb model is also highly sensitivity to market prices of lamb. The lamb are typically sold from November to February when range from $2.42 to $2.67 per pound at weights between 95 and 105 pounds, and are purchased from June to September when prices range from $2.51 to $2.84 per pound at weights around 68 pounds. As demonstrated in Table 14, if a farmer sells a lamb at the same price it was purchased at, it will always return a positive margin due to weight gained by the lamb during the pasture season. The auction model can realize strong returns when sale prices are much higher than purchase prices. If the purchase price is greater than the sale price, however, there is no offset by weight gain and a loss will be realized in most cases. Further sensitivity was conduction on the auction model's financial profitability around grazing fees of $212 to $374 per acre and sale prices

Table 11
Breeding lamb financial sensitivity – grazing fee & price vs. EBITDA margin.

Avg. Sale Price ($/lbs) \ Grazing Fee ($/Acre)	100	200	300	400	500
2.00	-7%	4%	13%	20%	26%
2.25	4%	12%	20%	26%	31%
2.50	12%	20%	26%	31%	36%
2.75	19%	26%	31%	36%	40%
3.00	26%	31%	36%	40%	43%
3.25	31%	36%	40%	43%	46%
3.50	35%	40%	43%	46%	49%
3.75	39%	43%	46%	49%	52%
4.00	43%	46%	49%	52%	54%

Table 12
Breeding & auction lamb operational sensitivity – stocking & energy density vs. flock size.

Energy Density (Acre/MW) \ Stocking Density (Heads/Acre)	6	7	8	9	10
3	900	1,050	1,200	1,350	1,500
4	1,200	1,400	1,600	1,800	2,000
5	1,500	1,750	2,000	2,250	2,500
6	1,800	2,100	2,400	2,700	3,000
7	2,100	2,450	2,800	3,150	3,500
8	2,400	2,800	3,200	3,600	4,000

Table 13
Breeding operational sensitivity - ewes retained & reproduction vs. EBITDA margin.

Reproduction Rate (Lambs per Ewe) \ Ewe Lambs Retained (% of Ewe Lambs)	10%	20.0%	30.0%	40.0%	50.0%
1.00	2%	-3%	-7%	-12%	-18%
1.25	14%	10%	6%	1%	-4%
1.50	22%	19%	14%	10%	5%
1.75	28%	25%	21%	17%	12%
2.00	33%	30%	26%	22%	17%
2.25	36%	33%	29%	25%	20%
2.50	39%	36%	32%	28%	24%
2.75	42%	38%	35%	31%	27%
3.00	44%	40%	37%	33%	29%

Table 14
Auction lamb financial sensitivity – selling and purchase price vs. EBITDA margin.

Purchase Price ($/lbs) \ Sale Price ($/lbs)	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
2.00	8%	17%	24%	30%	35%	40%	44%	47%	50%
2.25	0%	10%	18%	25%	30%	35%	39%	43%	46%
2.50	-7%	4%	12%	19%	25%	30%	35%	39%	42%
2.75	-14%	-3%	6%	14%	20%	26%	31%	35%	39%
3.00	-22%	-10%	0%	8%	15%	21%	26%	31%	35%
3.25	-29%	-16%	-6%	3%	10%	16%	22%	26%	31%
3.50	-36%	-23%	-12%	-3%	5%	11%	17%	22%	27%
3.75	-44%	-30%	-18%	-9%	0%	7%	13%	18%	23%
4.00	-51%	-36%	-24%	-14%	-6%	2%	8%	14%	19%

of $2.42 to $2.67 per pound on EBITDA margin. As displayed in Table 15, low sale prices can be offset by higher grazing fees. This can provide stability over volatile meat prices in downward market conditions. The analysis also highlights that EBITDA margins can reach much higher values than 10 % from the base case analysis. This provides farmers with an idea of what rates they should charge based on expected sales prices of lamb.

A key metric that affects farming production for the auction model is the amount of weight lambs gain per day on the pasture of 0.18–0.24 pounds per day. Table 16 demonstrates how EBITDA margins will be affected by this value and further exacerbated by different lamb purchase weights than the initial 68 pounds per lamb. Margins are directly tied to the amount of weight the lamb gains on the pasture, implying that high quality pasture can be critical for strong financial health. Solar developers should take this into account when designing PV farms intended for agrivoltaics sheep. This analysis also provides farmers with strategies towards how much weight each lamb must gain per day to ensure profitability based on how much they weighed when they were purchased. The goal is to purchase lighter lambs and grow them on the pasture, however, in most auctions, there is not a large supply of these lambs, so farmers must plan accordingly.

3.3. Capital cost analysis

The capital investment required to start a lamb grazing operation is similar for both the breeding and auction business models. The only difference in the auction lamb model is no investment in a breeding stock of ewes. This significantly reduces the initial investment of the operation, creating lower barriers to entry for this model.

For base case of the utility scale for the breeding model, as illustrated in Table 17, the D&A from the investment are tax deductible, but since this is a non-cash expense, it is added back to yield a 16 % ROI. This is greater than the 12.36 % agriculture production industry average ROI, implying that this would be a competitive investment. Furthermore, in the high case, ROI reaches as high as 31 % further strengthening the attractiveness of this investment. The low case, however, returns a 0 % ROI due to approximately $0 generated from operations. This would still be somewhat competitive with investments in the renewable energy services and equipment industry which earn a 2.18 % ROI.

For the auction model in Table 18, the base case for the utility scale of 22 % is greater than the breeding model due to the lower initial investment. This is also greater than the 12.36 % agriculture production industry average ROI, implying that this would be a competitive investment. Furthermore, in the high case, ROI reaches as high as 43 % further strengthening the attractiveness of this investment. The low case, however, returns a − 7 % ROI due to approximately negative cash generated from operations. This demonstrates the potential risk of the auction model due to volatile lamb prices.

Further investigation was conducted on each operations ability to service debt, detailed in Table 19 and Table 20. Both models could service debt with the available free cash flows from operations for the base case of the utility scale. In the high cases, the loan would provide additional tax shielding benefits from tax deductible interest payments. In the low case, however, the ROIC would be negative for both the auction and breeding models, therefore, interest payments could not be serviced by cash from operations and debt should not be used to finance the investment for these scenarios. The operation's ability to service its debt will increase equity returns to owners after the debt is repaid at

Table 15
Auction lamb financial sensitivity – grazing fee and sales price vs. EBITDA margin.

Avg. Sale Price ($/lbs) \	100	200	300	400	500
2.00	-21%	-15%	-8%	-3%	2%
2.25	-9%	-3%	2%	6%	10%
2.50	2%	6%	10%	14%	18%
2.75	10%	14%	18%	21%	24%
3.00	17%	21%	24%	26%	29%
3.25	24%	26%	29%	31%	34%
3.50	29%	31%	33%	36%	38%
3.75	33%	36%	38%	39%	41%
4.00	37%	39%	41%	43%	44%

Table 16
Auction lamb operational sensitivity - weight gain & initial weight vs. EBITDA margin.

Initial Weight (lbs) \ Weight Gain (lbs/day)	0.15	0.2	0.25	0.3	0.35
50	21%	26%	31%	35%	39%
55	16%	21%	26%	31%	35%
60	11%	17%	22%	27%	31%
65	6%	12%	18%	23%	27%
70	1%	7%	13%	18%	23%
75	-4%	3%	9%	14%	19%

Table 17
Breeding lambs capital investment and ROI.

Item	High	Base	Low
Scale		Utility Scale	
Breeding Lamb Investment:			
Breeding Stock	$323,832	$182,349	$104,530
Fencing	57,065	43,270	29,451
Vehicles	364,167	184,675	64,100
Water System	10,563	10,563	10,563
Mineral Feeder	840	840	840
Mobile Corral	70,000	65,000	60,000
Dogs	7200	5400	3600
Total Breeding Lamb Investment	**$833,666**	**$492,096**	**$273,083**
Investment per Ewe	*685*	*584*	*506*
Investment per Acre	*2826*	*1668*	*926*
EBITDA	**$286,670**	**$78,600**	**-$219**
D&A	150,480	84,641	43,316
Tax	27,919	0	0
Unlevered Free Cash Flow	**$258,751**	**$78,600**	**-$219**
Return on Investment	*31 %*	*16 %*	*0 %*

Table 18
Auction lamb capital investment and ROI.

Item	High	Base	Low
Scale		Utility Scale	
Auction Lamb Investment			
Total Breeding Lamb Investment	$833,666	$492,096	$273,083
Less: Breeding Stock	323,832	182,349	104,530
Total Auction Lamb Investment	**$509,834**	**$309,747**	**$168,553**
Investment per Acre	*1728*	*1050*	*571*
EBITDA	**$254,031**	**$70,806**	**-$12,595**
D&A	85,714	48,171	22,410
Tax	34,505	4018	0
Unlevered Free Cash Flow	**$219,526**	**$66,788**	**-$12,595**
Return on Investment	*43 %*	*22 %*	*−7 %*

Table 19
Breeding lamb ROIC and tax shield analysis.

Item	High	Base	Low
Debt	$833,666	$492,096	$273,083
Term	10 years	10 years	10 years
Interest Rate	7.06 %	7.06 %	7.06 %
Interest Expense	58,857	34,742	19,280
Tax	15,853	0	0
Levered Free Cash Flow	**$211,960**	**$43,858**	**-$19,498**
Annual Tax Shield	*12,066*	*0*	*0*
Return on Invested Capital	*25 %*	*9 %*	*−7 %*

Table 20
Auction lamb ROIC and tax shield analysis.

Item	High	Base	Low
Debt	$509,834	$309,747	$168,553
Term	10 years	10 years	10 years
Interest Rate	7.06 %	7.06 %	7.06 %
Interest Expense	35,994	21,868	11,900
Tax	27,126	136	0
Levered Free Cash Flow	**$190,910**	**$48,802**	**-$24,494**
Annual Tax Shield	*7379*	*3882*	*0*
Return on Invested Capital	*37 %*	*16 %*	*−15 %*

maturity, hence providing financing flexibility for investors.

A sensitivity analysis was conducted on economic factors like interest and tax rates to understand how the payback period would change under different economic conditions as demonstrated in Table 21 and Table 22. This was conducted on the high case for both models due to greater tax implications associated. In both cases, debt could be serviced at higher rates of interest without sacrificing significant returns. This is due to the tax shielding effects of greater interest, coupled with the strong EBITDA margins generated through the high case scenarios for both business models.

3.4. Tornado analysis

The financial analysis utilized a range of input to understand the high and low case sensitivities for each business model. To visualize the impact of these range in values on financial metrics tornado plots were developed and displayed in Fig. 3 and Fig. 4. This provides analysis on how much each high/low variable differs from the base case assumptions. For example, in both business models, meat sales demonstrated the largest deviations from the base case. This is due to the range of assumptions around sales prices, selling lamb weight, stocking density, weight gain, and others. Therefore, when creating projections and implementing strategies, farmers should shore up their assumptions around meat sales to ensure predictable and accurate sales. In both cases, gross profit margin represented one of the lowest deviations from the base case. This provides assurance over the direct costs to produce sales.

4. Discussion

4.1. Appropriate models for different types of farmers

Breeding lambs as a business model takes more time and effort to maintain since it is a full year operation. This requires more labour and employees staffed to maintain the flock during lambing and pasture seasons. It would, however, yield a higher margin compared to purchasing lambs from the auction since there are fewer costs associated with lamb born on the farm. This model will be best for farmers who can dedicate year-round time and effort to their flock and have the capital to invest in an initial breeding stock of ewes.

Purchasing lambs from the auction to grow on the pasture requires less labour due to its seasonality. There is no lambing period in this business model, so it is only utilized during the pasture season. This will yield lower margins compared to the breeding model since it requires the purchase of lambs from the auction. This model works well for farmers who have less time and effort to spend year-round on flock maintenance and supervision. It would also work well for farmers who need additional capacity of their flock to provide grazing services and fulfill contractual obligations with PV management and maintenance.

The largest driver of profitability for these business models is direct labour. At lower sizes of farms (25 MW or lower), less workers can be hired to maintain profitability. This leads farm managers/owners to be involved in daily farming operations to drive the business and keep costs down. As the farming operation scales, it can afford more labour, but manager's will be required to direct more attention to planning the strategy of the operation rather than farming duties.

Table 21
Breeding lamb capital investment analysis - tax and interest vs. ROIC.

Interest Rates \ Tax Rates	15.0%	17.5%	20.0%	22.5%	25.0%
4.0%	29%	28%	28%	28%	27%
5.0%	28%	27%	27%	27%	27%
6.0%	27%	27%	26%	26%	26%
7.0%	26%	26%	26%	25%	25%
8.0%	25%	25%	25%	25%	24%
9.0%	24%	24%	24%	24%	24%
10.0%	23%	23%	23%	23%	23%
11.0%	23%	22%	22%	22%	22%

Table 22
Auction lamb capital investment analysis - tax and interest vs. ROIC.

Interest Rates \ Tax Rates	15.0%	17.5%	20.0%	22.5%	25.0%
4.0%	41%	41%	40%	39%	39%
5.0%	41%	40%	39%	39%	38%
6.0%	40%	39%	38%	38%	37%
7.0%	39%	38%	38%	37%	36%
8.0%	38%	37%	37%	36%	36%
9.0%	37%	37%	36%	35%	35%
10.0%	36%	36%	35%	35%	34%
11.0%	36%	35%	34%	34%	33%

4.2. Scaling and impacts on economics

The results clearly show that both business models for solar sheep were highly profitable. As more and more solar sheep-based businesses are developed and grown in the case study region of Ontario, the profitability will be impacted. Lamb prices are driven heavily by the supply and demand of lamb in Ontario. A sudden influx of lamb into the market could have adverse affects on prices if there is not enough demand to match the supply [110].

Canada produced 16.6 thousand tonnes of mutton and lamb in 2022, while also importing 28.3 thousand more tonnes to meet the total demand [44]. Of the tonnes produced in Canada, 74 % are slaughtered provincially, meaning that it cannot be sold to large brand stores (Walmart, Costco) that require federally licensed slaughtered meat [111]. Increasing the amount of homegrown lamb that are processed through federally licensed butchers will allow the market to rely less on imported lamb and increase the supply of domestic, grass-fed lamb to the Canadian market and markets for export. Reducing imports have climate benefits of less transportation emissions and these emissions are further reduced if they are being offset by solar sheep [43]. Replacing imports with domestic solar sheep would provide more jobs locally for Canadians. For example, consider the number of additional jobs that would be created if all the existing solar farms converted to solar sheep. As of 2022, there were 4401 MW of installed PV power in Canada [112], which amounts to roughly 32,000 acres of land. If eight sheep and lamb are used per acre, around 257,000 heads would be needed to graze all the existing PV capacity in Canada. This accounts for 31 % of all sheep and lamb currently on farms in Canada [44]. The Canadian agriculture industry employed 276,977 people in 2021, while only 914 worked on sheep and goat farms [113]. Since sheep and lamb require six hours of labour each per year, if a worker works 12 h per day, 365 days per year, this would lead to 352 new workers needed to care for sheep and lambs on all solar sites in Canada. It is a 39 % increase in demand for sheep farm employees. In addition, solar sheep would provide lower costs to consumers through a simplified supply chain. In February 2023, the average import cost of lamb to Canada was US$8204 per ton [114]. This amounts to CAD$5.58 per pound. The average price at the Ontario auction in February 2023 was CAD$2.77 per pound [66]. Therefore, it costs roughly 2× more to import lamb than produce it locally. This cost is subsequently passed down to consumers. Canada imported $347.4 million worth of lamb and mutton in 2022 [44]. If this was produced locally, it could equal a cost savings of around $170 million. In a 2009 study, it was found that Canadian lamb producers were missing out on a $42 million opportunity in farm gate sales, and $250 million retail sales due to a lack of domestic supply [115]. To realize this opportunity, Canada can implement sheep grazing on all solar farms to increase domestic supply.

4.3. Limitations of this study

This study does have several limitations. First, since agrivoltaics is an emerging market in Canada, there are limited data points and business financial information accessible. Solar farms can be located on pastures of different quality which could have an impact on lamb growth and

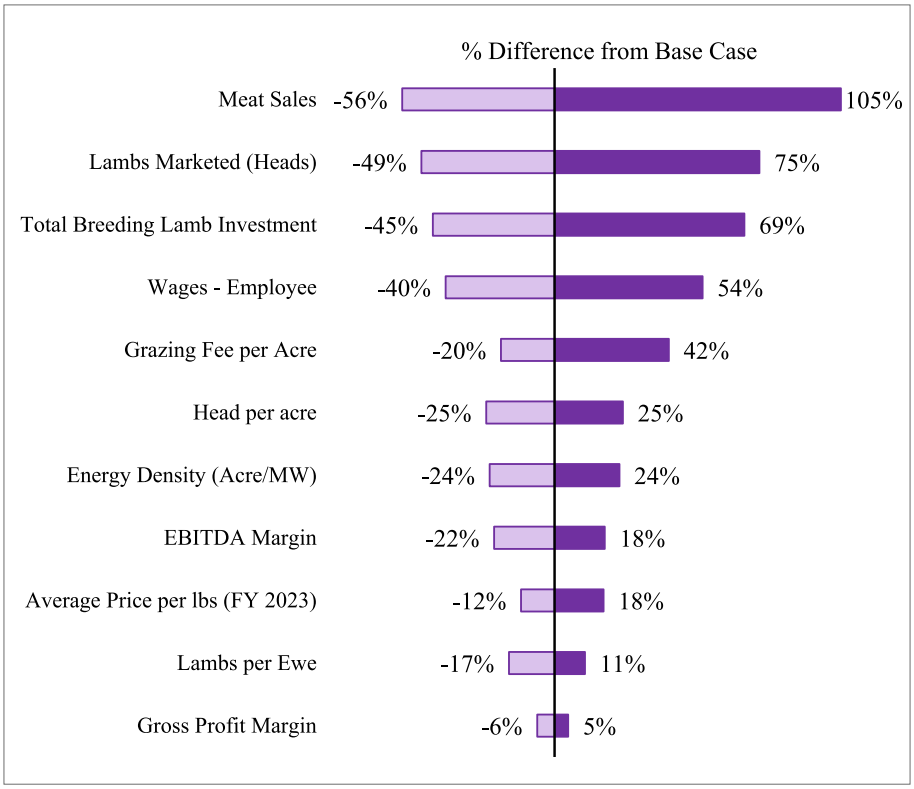


Fig. 3. Breeding Tornado Model – Utility Scale: High/Low vs. Base.

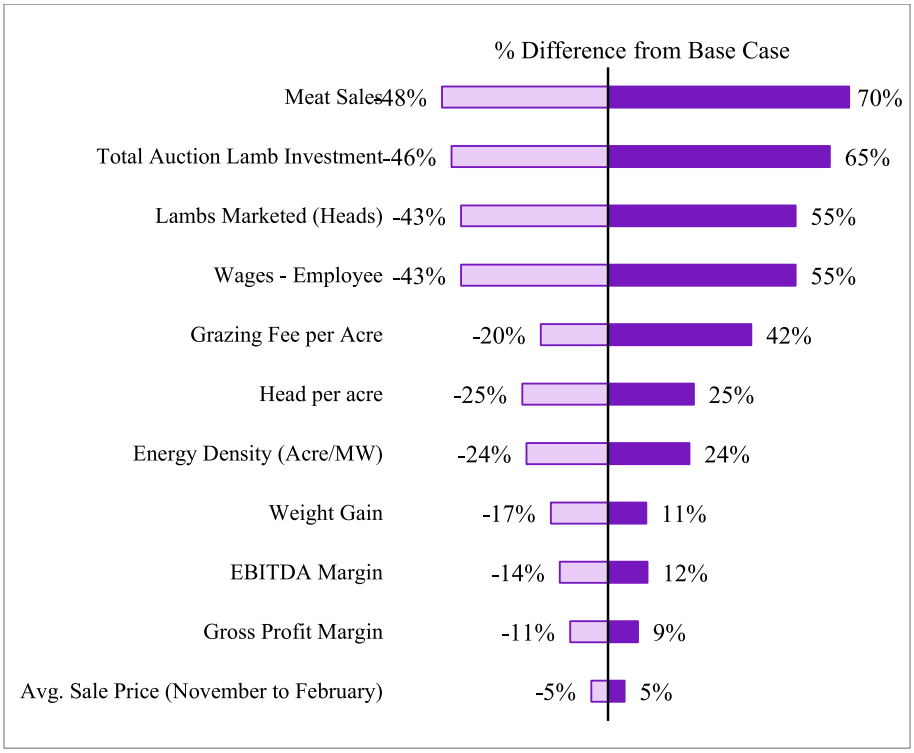


Fig. 4. Auction Tornado Model - Utility Scale: High/Low vs. Base.

fertilizer costs. These issues can be investigated in future work. In addition, economic and environmental optimization of agrivoltaics must also compare sheep-based agrivoltaics with crop based agrivoltaics. Agrivoltaics has been demonstrated with a wide variety of food types including: corn and maize [116,117], grapes [118], lettuce [119,120], and wheat [20]. As agrivoltaics creates a microclimate [119,121] that protect plants from too much solar radiation and reduce temperature for the plants [122] there is an increased water use efficiency with agrivoltaics [36] and in many cases an increase in crop yields: basil [123], broccoli [124], celery [125], chiltepin peppers [121], corn [116]/maize [117], lettuce [126], potatoes [127], spinach [123], strawberries [38] and tomatoes [121]. Agrivoltaics has the potential for all scales of greenhouses [128–132].

5. Conclusions

The integration of sheep grazing into PV farms offers a promising solution to land-use conflicts while simultaneously enhancing productivity and sustainability. This innovative approach presents a multifaceted opportunity for farmers, investors, and the environment. By utilizing pasture land beneath solar panels, agrivoltaics optimizes land use efficiency, mitigates global emissions, and improves public perception of renewable energy installations. Furthermore, with Canada's ample sheep supply, the nation has the potential to become a significant exporter of sustainably produced lamb, fostering economic growth and job creation in rural communities.

Financial analyses conducted on both breeding and auction lamb models within the agrivoltaics framework reveal compelling insights. Despite differences in operational approaches, both models demonstrate robust EBITDA margins that range from 10 % to 22 % for the auction model and 22 % to 40 % in the breeding model for normal and high upside scenarios. This surpasses the agriculture industry average of 7.32 % indicating strong cash generation compared to the industry. Furthermore, ROIs for the breeding model range for 16 % to 31 % and the auction 22 % to 43 % for the same scenarios. Compared to the agriculture production industry's average ROI of 12.36 %, these business models present competitive returns and attractive. While the breeding model exhibits higher EBITDA margins, the auction model offers greater ROI potential, reflecting the trade-offs between operational efficiency and initial investment costs. Notably, the sensitivity analyses conducted underscore the resilience of agrivoltaics to economic fluctuations, particularly in lamb prices, and interest and tax rates, highlighting its potential as a stable and profitable investment opportunity.

Moreover, the scalability of agrivoltaics presents an intriguing proposition, with fixed costs primarily tied to initial investments and variable costs dominated by operational expenses. While economies of scale may not be fully realized in the short term, the potential for increased profitability and ROI as operations expand suggests promising long-term prospects. Crucially, the success of agrivoltaics hinges on market conditions, with EBITDA margins subject to fluctuating lamb prices. With prudent management and strategic decision-making, however, agrivoltaic ventures stand to capitalize on market opportunities, ensuring profitability and sustainability in the long run.

In summary, agrivoltaics represents a transformative approach to agricultural and energy production, offering a synergistic solution that addresses environmental, economic, and social imperatives. By harnessing the power of solar energy alongside sustainable sheep farming practices, agrivoltaics not only unlocks new avenues for renewable energy deployment but also paves the way for regenerative land use practices and rural development. As nations worldwide seek to transition towards more sustainable energy systems, agrivoltaics emerges as a compelling model that reconciles the dual objectives of energy production and agricultural sustainability, ushering in a new era of innovation and progress in the renewable energy landscape.

CRediT authorship contribution statement

Adam Gasch: Writing – review & editing. **Rafael Lara:** Writing – review & editing. **Joshua M. Pearce:** Writing – review & editing.

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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