Supplementary information

Tailoring Australian carbon farming can realise greater co-benefits

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1. Case study farm information

1.1. Farm S1 (Campbell Town, Tasmania)

The S1 (TAS) farm had two flocks of self-replacing merino sheep (a wool and meat flock). GrassGro was parameterised for the wool flock with 41 kg ewes nominally stocked at 2.8 ewes ha^{-1}, while wethers were stocked at 2.7 wethers ha^{-1}. Ewes and wethers were replaced 1 Sep each year, with cast for age (CFA) ewes sold 31 Aug at 4 to 5 years of age and wethers sold 14 Oct at 5 to 6 years of age. Ewes were joined 22 Apr, with maiden ewes joined to lamb for the first time at two years of age, and a conception rate of 80% single-bearing ewes. All lambs were weaned 14 Jan with non-replacement ewe and wether lambs sold at 19 weeks. Shearing occurred 20 Jul for all animals, with breed characteristics of 4.65 kg greasy fleece, yielding 70% and a fibre diameter of 173 micron. The wool flock grazed 2,777 ha, separated into six paddocks of varying sizes and primarily contained Phalaris, subterranean clover, irrigated annual ryegrass, irrigated lucerne (*Medicago sativa*), weeping grass and wallaby grass (*Austrodanthonia spp*.). The CFA ewes from the wool flock were transferred to the meat flock at 4 to 5 years of age on the 1 Sep each year and thus remained with the wool flock until just prior to lambing. Meat flock ewes were bred to meat rams (Suffolk) before CFA 16 Dec at 6 to 7 years of age. Ewes were nominally stocked at 9.6 ewes ha^{-1}, joined 11 Apr, and a conception rate of 91% single and 2% twin-bearing ewes. Lambs were both 7 Sep, while weaned and sold 15 Dec. Shearing occurred 20 Jul, with breed characteristics of 4.15 kg greasy fleece, yielding 70% and a fibre diameter of 17.4 micron. The flock grazed three equally sized paddocks, with Phalaris and subterranean clover pastures. Additional GrassGro initialisation information is shown in Table S1.

1.2. Farm S2 (Meningie, South Australia)

The S2 (SA) farm was a predominantly merino sheep enterprise with a small cattle herd. After conversion of the cattle numbers to equivalent sheep DSE ha^{-1}, the GrassGro parameterised farm consisted of 67 kg merino ewes nominally stocked at 1.9 ewes ha^{-1} (Table S1). Unlike other farms, this farm purchases 70 kg ewes, aged 5 years on the 7 Sep each year, with the CFA ewes sold after two years on 17 Aug aged 7 to 8 years of age. Ewes were joined 1 Nov, with a conception rate of 86% single and 14% twin-bearing ewes. Lambs were born 29 Mar, weaned 23 Jun, with ewe lambs sold at a target liveweight of 60 kg between 27 Oct and 14 Nov, while wether lambs were sold at a target liveweight of 46 kg between 16 Aug and 30 Sep. The main flock were shorn 1 Jul while the weaners were shorn 15 Sep, with breed characteristics of 5.0 kg greasy fleece, yielding 68% and a fibre diameter of 20.7 micron. Paddocks primarily comprised lucerne and cocksfoot (*Dactylis glomerata*; 372.5 ha each) pastures, while a third paddock (120 ha) consisted of lucerne and perennial ryegrass.

1.3. Farm S3 (Ballarat, Victoria)

The VIC (S3) farm has two flocks of self-replacing merino ewes, a wool flock grazing 340 ha and a meat flock grazing 260 ha. The wool flock consists of 45 kg ewes, nominally stocked at 8.1 ewes ha^{-1}. Ewes are replaced 1 Jan and CFA 31 Dec at 6 to 7 years of age. Ewes were joined 19 Mar, with maiden ewes joined to lamb for the first time at two years of age, with a conception rate of 75% single and 25% twin-bearing ewes. Lambs were born 15 Aug, weaned 15 Nov, with wether lambs sold at 45 kg between 12 and 15 months of age. All wool flock ewe lambs were retained on farm, approximately 580 each year, and transferred to the meat flock 1 Jan, at 5 months of age and weighing 30 kg, to become maiden ewes for the meat flock. The meat flock ewe nominal stocking rate was 11 ewes ha^{-1}. Ewes were joined 16 Feb to meat rams (Dorset), maiden ewes joined to lamb at two years of age for the first time, with a conception rate of 60% single, 35% twin and 5% triple-bearing ewes. Meat flock CFA ewes were sold 31 Dec at 5 to 6 years of age. Meat flock lambs were born 14 Jul, weaned 1 Nov, and sold at 38 kg between 20 and 26 weeks of age. Shearing for the wool flock occurred 30 Apr, with breed characteristics of 4.3 kg greasy fleece, yielding 70% and a fibre diameter of 17.2 micron, while for the meat flock, shearing occurred 20 Apr with breed characteristics of 4.6 kg greasy fleece, yielding 70%a and a fibre diameter of 17.8 micron. A single set-stocked paddock was modelled for each flock. Pastures primarily consisted of perennial ryegrass, Phalaris and subterranean clover.

1.4. Farm S4 (Murrumbateman, New South Wales)

The S4 (NSW) farm is a self-replacing ultrafine merino enterprise. GrassGro was parameterised with 42 kg ewes, stocked at a nominal rate of 3.1 head ha^{-1}while wethers were stocked at 0.4 head ha^{-1} (Table S1). Ewes and wethers were replaced each 1 Apr, with Cast for Age (CFA) ewes sold 1 Mar at 5 to 6 years of age while CFA wethers were sold 1 Mar at 4 to 5 years of age. Ewes were joined 15 April, maiden ewes joined to lamb for the first time at two years of age, and a conception rate of 90% single- and 10% twin-bearing ewes. Lambs were born 4 Sep, weaned 1 Dec, with non-replacement ewe and wether lambs sold at 52 weeks of age. Shearing occurred 1 Aug with breed characteristics being 3.52 kg greasy fleece, yielding 72%, and a fibre diameter of 14 micron. A single set-stocked paddock was implemented. Pasture species primarily comprised Weeping grass (*Microlaena spp.*), subterranean clover (*Trifolium subterraneum*) and Phalaris (*Phalaris aquatica*).

1.5. Farm S5 (Kulin, Western Australia)

The S5 (WA) farm consisted of both livestock and cropping enterprises, with the cropping area removed from modelling although we assumed that some supplementary feed was derived from the cropping area. There are two flocks of self-replacing sheep, a merino/composite wool flock and a self-shedding meat flock with each modelled separately in GrassGro and allocated half of the total grazing area each. The 70 kg ewe wool flock was parameterised with a nominal stocking rate of 1.1 head ha^{-1}. Ewes were replaced each 28 Dec, with CFA ewes sold 1 Dec at 5 to 6 years of age. Ewes were joined 19 Dec, with maiden ewes joined to lamb for the first time at two years of age, and a conception rate of 78% single- and 22% twin-bearing ewes. Lambs were both 16 May, weaned 1 Oct, with all non-replacement lambs sold at a target liveweight of 45 kg; ewe lambs sold between 34 and 48 weeks of age while the wether lambs were sold between 27 and 48 weeks of age. Shearing occurred 30th Jan to 1st Feb each year, with breed characteristics being 7.5 kg greasy fleece, yielding 72%, and a fibre diameter of 21 micron. The meat flock lost wool naturally and consisted of 70 kg ewes with a nominal stocking rate of 1.1 head ha^{-1}. Ewes were replaced each 20 Jan, with CFA ewes sold 22 Dec at 4 to 5 years of age. All ewes were joined 4 Feb, with maiden ewes joined to lamb for the first time at two years of age, and a conception rate of 48% single and 52% twin-bearing ewes. Lambs were born 2 Jul, weaned 10 Nov, with all non-replacement ewe and wether lambs sold between 30 and 43 weeks of age once they achieved a target liveweight of 55 kg. As the flock did not produce viable wool (lost naturally), we assumed no saleable fleece from the meat flock. A single set-stocked paddock was modelled for each flock. Predominant pasture species included subterranean clover, annual ryegrass (*Lolium multiflorum*) and Capeweed (*Arctotheca calendula*).

1.6. Farm S6 (Warrnambool, Victoria)

The S6 (VIC) farm is located near Warrnambool in a medium-high rainfall zone. The GrassGro parameterised self-replacing merino flock consisted of 45 kg ewes nominally stocked at 9.8 ewes ha^{-1} while wethers were stocked at 9.8 wethers ha^{-1}. Ewes and wethers were replaced 1 Jan each year, with CFA ewes sold 30 Nov at 5 to 6 years of age while CFA wethers were sold 30 May at 5 to 6 years of age. All ewes were joined 9 Apr, with maiden ewes joined to lamb for the first time at two years of age, and a conception rate of 90% single and 10% twin-bearing ewes. Lambs were born 5 Sep, weaned 29 Nov, with non-replacement ewe and wether lambs sold at 34 and 12 weeks of age, respectively. Shearing occurred 15 Dec for the mature animals and 1 Dec for the weaners, with breed characteristics of 4.95 kg greasy fleece, yielding 74% and a fibre diameter of 17 micron. A single set-stocked paddock was implemented. Pasture species primarily consisted of perennial ryegrass (*Lolium perenne*), Phalaris and subterranean clover.

1.7. Farm S7 (Naracoorte, South Australia)

The S7 (SA) case study farm is equally located across the SA and VIC border, in a medium rainfall zone. The GrassGro farm was parameterised as a self-replacing Border Leicester x Merino flock with 60.3 kg ewes stocked at 14.3 ewes ha^{-1}. Ewes were replaced 15 Feb every year, with CFA ewes sold 15 Oct at 5 to 6 years of age. All ewes were joined 15 Feb, with a conception rate of 55% single and 45% twin-bearing ewes. Unlike all other farms modelled, this farm's maiden ewes were joined to lamb for the first time at one year of age. Lambs were both 13 Jul, weaned 1 Nov, with non-replacement ewe lambs sold at a target liveweight of 37.5 kg between 20 and 25 weeks while wether lambs were sold at a target liveweight of 40 kg between 20 and 24 weeks. Shearing occurred 15 Dec, with breed characteristics of 3.87 kg greasy fleece, yielding 75% and a fibre diameter of 29.5 micron. A set-stocked paddock was implemented. Pasture species primarily comprised perennial ryegrass and subterranean clover.

Table S1. GrassGro initialisation data. Sheep farms abbreviated by number (Sx = Sheep farm number x) and State (TAS = Tasmania, SA = South Australia, VIC = Victoria, NSW = New South Wales, WA = Western Australia, SA = South Australia). DAP = diammonium phosphate, DM = dry matter, MAP = monoammonium phosphate, ME = metabolisable energy, MJ = megajoules, SSP = single superphosphate.

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Total area (ha)	3,170 split between 2,777 for wool flock and 393 for meat flock	865 split between paddocks 1 & 2 @ 372.5 each and paddock 3 @ 120	600 split between wool flock (340 ha) and meat flock (260 ha)	160	3,484 equally split between wool and meat flocks	440	1880
Number of paddocks	6 for wool flock (Paddocks (P) 1-6), 3 for meat flock (P7-P9)	3	1	1	1 per flock	1	1
Steepness of farm	Gentle (P2 & P4), level all other paddocks	Level	Level	Level	Level	Level	Level
Fertility scalar (0-1 scale)	0.85	0.53 for paddock 1 & 2, 0.72 for paddock 3	0.8	0.9	0.9	0.9	1.0

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Topsoil	All paddocks	All paddocks	Both flocks the same		Both flocks the same		
Cumulative depth (mm)	300	200	150	150	150	150	150
Field capacity (m^3 m^{-3})	0.28	0.22	0.46	0.3	0.3	0.3	0.36
Wilting point (m^3 m^{-3})	0.09	0.09	0.31	0.15	0.15	0.15	0.15
Bulk density (mg m^{-3})	1.3	1.44	1.2	1.4	1.4	1.4	1.3
Saturated hydraulic conductivity (mm hr^{-1})	30	300	1	60	60	60	50
Initial water (m^3 m^{-3})	0.15	0.14	0.15	0.15	0.15	0.15	0.15
Subsoil	All paddocks	All paddocks	Both flocks the same		Both flocks the same		
Cumulative depth (mm)	1200	800 for paddocks 1 & 2, 1000 paddock 3	1250	1000	1000	1000	1000
Field capacity (m^3 m^{-3})	0.33	0.18	0.48	0.34	0.34	0.34	0.33
Wilting point (m^3 m^{-3})	0.21	0.08	0.33	0.23	0.23	0.23	0.15

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Bulk density (mg m^{-3})	1.5	1.6	1.2	1.6	1.6	1.6	1.4
Saturated hydraulic conductivity (mm hr^{-1})	10	300	0.1	2	2	2	50
Initial water (m^3 m^{-3})	0.28	0.32	0.23	0.23	0.23	0.23	0.23
Pasture details			Both flocks the same		Both flocks the same		
Pasture 1	Phalaris (P1: 800 ha, P3: 64 ha, P4: 262 ha, P7-P9 131 ha each)	Lucerne-winter active (paddocks 1 & 2)	Perennial ryegrass	Annual grass- Early	Annual ryegrass	Perennial ryegrass	Phalaris
Phenology	Vegetative	Vegetative	Vegetative	Senescent	Senescent	Semi-Dormant	Reproductive
Live DM (kg ha^{-1})	1500	1000	400	1000	0	0	1000
Standing dead DM (kg ha^{-1})	500 (P1, P3, P4); 3000 (P7-P9)	1000	900	3000	1500	5000	1250
Litter DM (kg ha^{-1})	500	500	200	50	500	200	1000
Below ground DM (kg ha^{-1})	200	600	300	1000	0	200	1000
Maximum root depth (mm)	750	700	600	575	1000	550	1000

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Seed DM (kg ha^{-1})	-	-	-	300	100	-	-
Pasture 2	Sub Clover-Seaton Park (P1: 800 ha, P4: 262 ha, P7-P9 131 ha each)	Cocksfoot (paddocks 1 & 2)	Phalaris	Sub Clover-Seaton Park	Sub Clover-Seaton Park	Phalaris	Sub Clover-Leura
Phenology	Vegetative	Vegetative	Vegetative	Senescent	Senescent	Semi-Dormant	Senescent
Live DM (kg ha^{-1})	500 (P1, P7-P9), 750 (P4)	500	600	0	0	0	0
Standing dead DM (kg ha^{-1})	500 (P1, P4), 1500 (P7-P9)	1000	1100	1000	2000	1500	2000
Litter DM (kg ha^{-1})	500	200	400	200	200	500	200
Below ground DM (kg ha^{-1})	200	300	800	500	0	200	2000
Maximum root depth (mm)	500 (P1, P7-P9), 440 (P4)	800	1000	1000	600	800	1000
Seed DM (kg ha^{-1})	1000 (P1, P4), 800 (P7-P9)	-	-	1000	800	-	150
Pasture 3	Austrodanthonia (P2: 1553 ha)	Lucerne (paddock 3)	Sub Clover-Leura	Microlaena	Capeweed	Sub Clover-Leura	Perennial ryegrass

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Phenology	Vegetative	Vegetative	Vegetative	Vegetative	Senescent	Senescent	Reproductive
Live DM (kg ha^{-1})	1500	2000	300	500	0	0	0
Standing dead DM (kg ha^{-1})	500	1000	400	200	500	3000	100
Litter DM (kg ha^{-1})	500	500	300	100	300	200	200
Below ground DM (kg ha^{-1})	200	1000	200	600	0	0	700
Maximum root depth (mm)	790	900	300	500	500	600	750
Seed DM (kg ha^{-1})	-	-	-	-	150	100	-
Pasture 4	Microlaena (P2: 1553 ha)	Perennial ryegrass to reflect barley	n/a	Phalaris	n/a	n/a	n/a
Phenology	Vegetative	Vegetative		Semi-dormant			
Live DM (kg ha^{-1})	750	2000		0			
Standing dead DM (kg ha^{-1})	500	1000		500			
Litter DM (kg ha^{-1})	500	200		400			
Below ground DM (kg ha^{-1})	200	500		700			

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Maximum root depth (mm)	450	600		500			
Pasture 5	Irrigated lucerne- semi winter active (P5: 67ha)			n/a			
Phenology	Vegetative						
Live DM (kg ha^{-1})	1500						
Standing dead DM (kg ha^{-1})	500						
Litter DM (kg ha^{-1})	500						
Below ground DM (kg ha^{-1})	200						
Maximum root depth (mm)	900						
Pasture 6	Irrigated wheat (Annual ryegrass in GrassGro; P6: 31 ha)						
Phenology	Vegetative						
Live DM (kg ha^{-1})	1200						
Standing dead DM (kg ha^{-1})	500						

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Litter DM (kg ha^{-1})	500						
Below ground DM (kg ha^{-1})	200						
Maximum root depth (mm)	520						
Ewe breed	Small merino	Large Merino	Medium merino	Small merino	Large merino	Small merino	Border Leicester x merino
Ram breed	Small merino	Border Leicester	Medium merino	Small merino	Large merino	Small merino	Border Leicester x merino
Standard reference weight of rams (kg)	57.4	95.0	63.0	58.8	98.0	63.3	84.4
Death rate: adults (% $year^{-1}$)	1.0	1.0	2.0	4.0	2.0	2.0	2.7
Death rate: weaners (% $year^{-1}$)	1.0	1.0	2.0	4.0	2.0	2.0	2.0
Stock details- meat flock							
Ewe breed	Small merino	n/a	Medium merino	n/a	Border Leicester x Merino	n/a	n/a
Ram breed	Suffolk		Dorset		Border Leicester x Merino		

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Standard reference weight for rams (kg)	110.0		77.0		98.0		
Death rate: adults (% year^{-1})	1.0		2.0		2.0		
Death rate: weaners (% year^{-1})	1.0		2.0		2.0		
Maintenance feeding rules (same for both flocks unless listed differently)							
Location of supplementary feeding	Paddock	Paddock	Paddock	Paddock	Feedlot	Paddock	Paddock
Mature females	If condition falls to 2.5, feed 1-Jan to 31-Dec	If condition falls to 3.0, feed 15-Feb to 30-Mar,if condition falls to 1.5 31 Mar to 14 Feb, or if feed DM < 750 kg ha^{-1}	If condition falls to 2.0, feed 1-Jan to 31-Dec	If condition falls to 2.0, feed 1-Jan to 31-Dec	If condition falls to 2.0, feed 1-Jan to 31-Dec	If condition falls to 2.0, feed 1-Jan to 31-Dec	If condition falls to 2.0, feed 1-Jan to 31-Dec

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Mature males	If condition falls to 2.0, feed 1-Jan to 31-Dec	n/a	n/a	As per mature females	n/a	If condition falls to 0.5, feed 1-Jan to 31-Dec	n/a
Immature females	As per mature females	As per mature females	As per mature females	As per mature females	As per mature females	As per mature females	As per mature females
Immature males	As per mature males	If condition falls to 2.0, feed 1-Jan to 31-Dec	If condition falls to 1.0, feed 1-Jan to 31-Dec	As per mature females	Fed in paddock if condition falls to 1.0 during 1-Jan to 31-Dec	As per mature males	If condition falls to 1.0, feed 1-Jan to 31-Dec
Weaner flock	As per mature females (n/a meat flock)	As per immature weaners, or if feed DM < 500 kg ha^{-1}	As per mature females	n/a	Fed in paddock if condition falls to 2.0 during 1-Jan to 31-Dec	As per mature females	As per mature females
Supplement blend and percentage	Wool flock: Wheat grain (100%); Meat flock (wheat grain 78% & hay 22%)	Silage (100%)	Silage (100%)	Hay (100%)	Barley straw (90%) & Lupins (10%)	Barley grain (90%) and field beans (10%)	Silage (85%) & hay (15%)

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Dry matter (DM) content (%)	88; 88	60	27	86	87	89	36
Dry matter digestibility (%)	81; 81	80	67	53	68	92	62
Metabolisable energy (MJ ME kg DM^{-1})	12.5; 12.3	12.1	10.0	7.7	10.5	14.0	9.2
Crude protein (%)	12; 12	18	16	20	10	13	14
Rumen-degradable protein (%)	88; 88	80	80	65	55	86	76
Production feeding rule 1 (same for both flocks unless listed differently)	Ewes	n/a	All stock	All stock	Young stock	Ewe weaners	Ewes
Location of supplementary feeding	Paddock wool flock; Feedlot meat flock		Paddock	Paddock	Paddock	Paddock	Paddock
Rate & conditions	Fixed amount of 0.52 kg day^{-1} from 15-Jan to 15-Apr		Ad libitum from 1-Jan to 1-May, start when available DM < 1500 kg ha^{-1} and finish when	Fixed amount of 0.05 kg day^{-1} from 1-Jun to 31-Jul	Target from 1-Jan to reach 42 kg 1-Apr (wool flock), Target from 1-Jan to each 50 kg 30-Apr (meat flock)	Fixed amount of 0.06 kg day^{-1} from 1-Dec to 31-Dec	Fixed amount of 0.33 kg day^{-1} from 1-Feb to 28-Feb

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
			available DM > 2000 kg ha^{-1}				
Supplement blend and percentage	Wheat grain (78%) and hay (22%)		Field beans (70%) & silage (30%)	Hay (100%)	Barley grain (80%) & Lupins (20%)	Barley grain (90%) and field beans (10%)	Lupins (100%)
Dry matter (DM) content (%)	88		69	86	89	89	88
Dry matter digestibility (%)	81		80	53	76	92	80
Metabolisable energy (MJ ME kg DM^{-1})	12.3		12.1	7.7	12.1	14	13.3
Crude protein (%)	12		25	20	16	13	28
Rumen-degradable protein (%)	88		89	65	81	86	75
Production feeding rule 2 (same for both flocks unless otherwise stated)	n/a	n/a	n/a	n/a	Ewes	Ewe weaners	n/a
Location of supplementary feeding					Paddock	Paddock	
Rate & conditions					Ad libitum feed from 1-	Fixed amount of	

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
					Dec to 22-Dec when available green DM < 500 kg ha^{-1}, end feeding when available green DM > 1,000 kg ha^{-1}	0.14 kg day^{-1} from 1-Feb to 31-Mar	
Supplement blend and percentage					Barley grain (70%) & barley straw (30%)	Barley grain (90%) and field beans (10%)	
Dry matter (DM) content (%)					88	89	
Dry matter digestibility (%)					76	92	
Metabolisable energy (MJ ME kg DM^{-1})					11.4	14	
Crude protein (%)					10	13	
Rumen-degradable protein (%)					80	86	
Production feeding rule 3 (same for both flocks unless otherwise stated)	n/a	n/a	n/a	n/a	Ewes	Ewe weaners	n/a

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Location of supplementary feeding					Paddock	Paddock	
Rate & conditions					Ad libitum feed from 23-Dec to 1-Mar when available green DM < 500 kg ha^{-1}, end feeding when available green DM > 1,000 kg ha^{-1}	Fixed amount of 0.16 kg day^{-1} from 1-Apr to 30-Apr	
Supplement blend and percentage					Barley straw (80%) and barley grain (20%)	Barley grain (90%) and field beans (10%)	
Dry matter (DM) content (%)					87	89	
Dry matter digestibility (%)					59	92	
Metabolisable energy (MJ ME kg DM^{-1})					8.5	14	
Crude protein (%)					9	13	

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Rumen-degradable protein (%)					58	86	
Production feeding rule 4 (same for both flocks unless listed differently)	n/a	n/a	n/a	n/a	Ewes	n/a	n/a
Feeding rule fed where					Feedlot		
Rate & conditions					Ad libitum feed from 2-Mar to 20-Apr (wool flock) or from 2-Mar to 30-Apr (meat flock) when available green DM < 500 kg ha^{-1}, end feeding when available green DM > 1,000 kg ha^{-1}		
Supplement blend and percentage					Barley grain (90%) & lupins (10%)		

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
					plus urea mineral lick		
Dry matter (DM) content (%)					87		
Dry matter digestibility (%)					68		
Metabolisable energy (MJ ME kg DM^{-1})					10.5		
Crude protein (%)					12		
Rumen-degradable protein (%)					55		
Grazing rules	Wool flock rotational graze based on withhold 14 days, check every 4 days and move when weight gain margin > 0.02 kg day^{-1}. Ewes & weaners: 1-Jan to 14-Jan P1 & P4, 15-Jan to 30-Apr P1, P3-P5, 1-May to 30-Jun P1,P3-P4 & P6,	Rotational grazing based on 7-day rotations. Ewes: 1-May to 31-Aug in paddocks 1 and 2, 1 Sep to 15 Oct in paddock 1, 16-Oct to 14-Nov in	Set-stocked	Set-stocked	Set-stocked	Set-stocked	Set-stocked

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
	1-Jul to 31-Aug P1, P4 &P6, 1-Sep to 31-Dec P1, P4 & P6. Wethers: 1-Jan to 14-Jan P1 & P4, 15-Jan to 14-Mar P1, P3-P4, 15-Mar to 30-Apr P1-P4, 1-May to 30-Jun P1-P4 & P6, 1-Jul to 31-Aug P1-P2, P4 & P6, 1-Sep to 31-Dec P1 & P4. Meat flock rotationally graze all paddocks year-round based on withhold for 14 days, check every 4 days and move when weight gain margin > 0.025 kg day^{-1}	paddocks 1 & 2, 15-Nov to 30-Apr in all paddocks. Weaners: 23-Jun to 31-Aug in paddock 3, 1-Sep to 15-Oct in paddock 2, 16-Oct to 14-Nov in paddock 3, 15-Nov to 22-Jun in paddocks 1 & 2.					

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
Irrigation	P5 and P6 only: Fill to 0.95 field capacity with 18 mm between 1-Sep and 31-Mar						Approx 8% of the farm is irrigated, but for ease of modelling, we increased the soil fertility scalar to reflect additional feed supply from this paddock
Silage & hay conservation	Wool flock hay: Close P5 (hay-cutting) and P6 (reflect grain harvest) 1-Sep, stock cutting 31-Dec, cut 10th Nov to 100 mm, 100% of forage gathered, and don't cut if whole farm DM < 800 kg ha^{-1}. Meat flock hay: Close 1	Silage: Close paddock 3 1-Sep, stock cutting 15-Oct when DM yield > 1000 kg ha^{-1}, cutting to 50 mm, 100% of forage					

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
	paddock per year or rotating basis on 16-Dec and stop cutting 2-Feb, cut 16-Dec to 100 mm, 95% of forage gathered, and don't cut if whole farm Dm < 700 kg ha^{-1}	gathered, and don't cut if whole farm DM < 800 kg ha^{-1}					
Key inputs							
Diesel (litres)	12,000	6,000	7,000	1,300	10,000	1,800	62,000
Unleaded fuel (litres)			2,000	700			
Electricity (kWh)	118,500	15,400	12,000	4.2	3,263	8,000	157,000
Purchased hay (t DM)				2.1			
Purchased grain (t DM)	200					58.3	
Purchased lupins or field beans (t DM)			306		65.9	6.5	206.3
Urea fertiliser (t)	116	10					16.3
SSP fertiliser (t)	202	43.3	110	2.6	47		97.75

Property details	**S1 (TAS)**	**S2 (SA)**	**S3 (VIC)**	**S4 (NSW)**	**S5 (WA)**	**S6 (VIC)**	**S7 (SA)**
DAP fertiliser (t)		8					
MAP fertiliser (t)			6			32	
Lime (t)			100				
Home-grown hay, silage or straw (t DM)	125	104.2	211.8		390		160.9 (hay) & 911.6 (silage)
Home-grown grain (t DM)	240				89		
Purchased ewes	GrassGro estimate 1,896 from wool flock	556	GrassGro estimate 605 from wool flock				

2. Economic analysis

2.1. Meat prices

Time series data (2012-2023 inc.) were extracted from the MLA database (www.mal.com.au/prices-markets/statistics/), assuming a 47% dressing percentage[1] to determine meat sales prices. ANOVA was performed to investigate differences in price data between states, sale destinations, or weight ranges. As the analysis showed significant differences between the states for the same livestock class, state-level data was used. Using farm data, we matched the price with the class of livestock sold and their likely destinations, i.e., abattoir or saleyard. Each livestock class price time series was adjusted for inflation using the Consumer Price Index obtained from the Australian Reserve Bank[2]. From that, mean historic price was calculated and used as the most likely price, and the 25th and 75th percentiles were calculated and assumed to represent low and high price scenarios (Table S2).

Table S2. Low and high meat liveweight price (AUD kg liveweight^{-1}) for the case study farms. Prices are shown for each animal class and farm (S1-7).

Case study farm	Stock class	Low price (AUD kg LW^{-1})	High price (AUD kg LW^{-1})
S1	Wethers	1.72	2.91
	Ewes	1.35	2.48
	Lambs	2.88	3.58
S2	Ewes	1.31	2.52
	Lambs	2.82	3.72
S3	Ewes	1.41	2.42
	Lambs	2.66	3.75
S4	Wethers	1.62	2.82
	Ewes	1.60	2.66
	Lambs	2.74	3.75
S5	Merino & crossbred ewes	1.47	2.54
	Merino & crossbred lambs	2.18	3.22
S6	Wethers	1.47	2.35
	Ewes	1.41	2.42
	Wether lambs (18-24 kg)	2.90	3.89
	Ewe lambs (24-30 kg)	2.89	3.87
S7	Ewes	1.31	2.52
	Lambs	2.82	3.72

2.2. Wool prices

We standardised wool prices across farms, based on data sourced from the Australian Wool Exchange (www.awex.com.au/market-infomation/awex-wool-market-indicators/; Table S3). These were cross-checked with the farmer data to ascertain that prices were similar to those collected. An exponential curve (wool price = $17190e^{-0.115x}$) was used to extrapolate wool prices outside the source range of between 17 and 32 microns, resulting in estimated prices ranging from 4,850 and 400 AU cents kg clean fleece weight^{-1}.

Table S3. Wool prices as a function of fibre diameter. Prices are given for each farm (S1-7) and multiple fibre diameters.

Wool fibre diameter (µ)	Farms with the majority of wool at this price	AU cents kg clean fleece weight^{-1}
32		400.8
30	S7	577.2
28		685.2
25		1,003.7
23		1,258.2
21	S5, S2	1,678.4
20		1,733.0
19		1,901.8
18	S1, S3	2,016.1
17	S6	2,407.4
14[a]	S4	3,436.1[a]
11[a]	S4	4,851.7[b]

[a] Price for baseline and all interventions except the farm-specific intervention of single lambing combined with reduced micron wool when extrapolated from the exponential curve equation when plotting 17 to 32 micron wool prices; [b] Price used for the farm-specific intervention of single lambing combined with reduced micron wool when extrapolated from the exponential curve equation when plotting 17 to 32 micron wool prices.

2.3. Farm input and management costs

For farm inputs, stock husbandry and selling costs (meat and wool), we assumed a standardised price across all farms such that economic differences in results would be due to effects of the interventions, rather than to differences in price/cost assumptions (Table S4).

In addition, there are several farm-specific costs associated with the baseline farm system (Table S5). Where a key farm input may be reduced with an intervention, such as spray and weed control for the 10% trees on farm intervention, the cost is reduced by 10%. Where the case study farmer supplied a total cost, for example, mineral lick, this was divided by the number of animals supplied the lick to determine AUD head^{-1}. This allowed us to alter total price as livestock numbers altered with an intervention.

Table S4. Prices of farm inputs, animal husbandry and selling costs. Prices were used for all farms in the analysis for each baseline and interventions where appropriate.

	Price	Unit
Single superphosphate	600	AUD t^{-1}
Mono-ammonium phosphate	1,450	AUD t^{-1}
Di-ammonium phosphate	850	AUD t^{-1}
Urea	500	AUD t^{-1}
Lime	100	AUD t^{-1}
Cattle manure	50	AUD t^{-1}
Electricity	0.3	AUD kWh^{-1}
Diesel	1.86	AUD $litre^{-1}$
Unleaded fuel	1.94	AUD $litre^{-1}$
Purchased hay	300	AUD t DM^{-1}
Purchased lupins	400	AUD t DM^{-1}
Purchased wheat[a]	437	AUD t DM^{-1}
Purchased field beans/grain mix	300	AUD t DM^{-1}
On-farm conserved stubble	35	AUD t DM^{-1}
On-farm conserved silage	125	AUD t DM^{-1}
On-farm conserved hay	90	AUD t DM^{-1}
Animal health (ewes)[b]	3.43	AUD $head^{-1}$
Animal health (wethers)[b]	4.67	AUD $head^{-1}$
Marking (ewe lambs)[c]	1.95	AUD $head^{-1}$
Marking (wether lambs)[c]	2.85	AUD $head^{-1}$
Shearing (mature animals)[d]	9.14	AUD $head^{-1}$
Shearing (young stock)[d]	7.89	AUD $head^{-1}$
Livestock sales commission	0.045	AUD AUD $revenue^{-1}$
Wool sales commission	0.15	AUD kg clean fleece $weigh\ sold^{-1}$
Livestock levies	5	AUD $head\ sold^{-1}$

[a] Assumed the same price for farm-grown wheat fed to the flock as a lost opportunity cost; [b] Based on drenching, vaccination etc for livestock with an increase in the amount of drenching required for wethers compared with ewes; [c] Additional AUD 0.90 for wether lambs for castration, including additional pain relief, relative to ewe lambs; [d] All associated costs of shearing such as wool-classer, shed sundries, wool packs etc plus cost AUD 1.25 $head^{-1}$ for crutching, with no crutching for young stock in their first year.

Table S5. Farm-specific costs (AUD annum^{-1}) for the baseline farm system. Values were specified by each case study farmer. S1-7 represents farm abbreviations.

Farm	Input	Total cost (AUD annum^{-1})
S1	Repairs and maintenance	424,000
	Spray and weed control	90,000
	Pasture renovation	103,130
	Handling/contractors	20,000
	Breeding costs	19,123
S2	Repairs and maintenance	5,200
	Spray and weed control	16,128
	Sowing	13,213
	Pasture renovation	27,500
	Handling/contractors	3,609
	Transport	13,139
	Supplements	17,518
	Ewe replacements	97 & 187[a]
S3	Repairs and maintenance	18,455
	Sowing	19,678
	Transport	7,749
S4	Repairs and maintenance	13,475
	Spray and weed control	650
	Pasture renovation	3,665
	Stock handling/contractors	1,707
	Mineral supplement	1,550
S5	Repairs and maintenance	20,000
	Spray and weed control	10,000
	Pasture renovation	20,000
	Transport- livestock	12,156
	Transport- wool	1,210
	Mineral lick	20,000
S6	Breeding costs	22,274
	Repairs and maintenance	8,000
	Spray and weed control	5,000
	Pasture renovation	53,600
S7	Repairs and maintenance	74,000
	Pasture renovation	10,000
	Irrigation water	75,000
	Stock handling/contractors	24,000
	Bulk goods transport	7,000

[a] LSP and HSP to match low and high sheep selling prices

2.4. Costs of livestock feed supplement (3-NOP and *Asparagopsis*)

The cost of 3-NOP implementation was assumed to be AUD 0.09 head^{-1} day^{-1} based on:

- AUD 0.03 head^{-1} day^{-1} for the active ingredient (dose rate scaled down based on cattle costing AUD 0.30 head^{-1} day^{-1} and sheep being ~ 10% liveweight, and therefore intake, of cattle)[3],

- AUD 0.06 head^{-1} day^{-1} for delivery of supplement (based on pellets and on-farm labour delivery costing AUD 550 t DM^{-1} and feeding 100 grams DM head^{-1} day^{-1}).

The cost of *Asparagopsis* implementation was assumed to be AUD 0.16 head^{-1} day^{-1} based on:

- AUD 0.10 head^{-1} day^{-1} for the active ingredient (dose rate scaled down based on cattle costing AUD 1.00 head^{-1} day^{-1} and sheep being ~ 10% liveweight, and therefore intake, of cattle)[4],
- AUD 0.06 head^{-1} day^{-1} for delivery of supplement (based on pellets and on-farm labour delivery costing AUD 550 t DM^{-1} and feeding 100 grams DM head^{-1} day^{-}).

2.5. Establishment costs for planting environmentally appropriate trees on farm

We considered potential income from carbon credits that converting land use from grazing to environmental plantings would generate. We consider two costs: a) the cost of establishing and maintaining the new land use (e.g. the cost of establishing and maintaining a new carbon woodland), and b) the cost forgone from no longer using the land in the current agricultural use (i.e. the value of returns net of cost from current grazing that will no longer be possible once land is converted to carbon woodland). Economic analyses were conducted assuming that planting of trees related to environmentally appropriate species ("environmental plantings") which occurred within a framework of broader farm budgeting considering a range of other simultaneous interventions on farm and their impacts on carrying capacity. As such, the reduction in sheep numbers that would be associated with environmental plantings are accounted for in the farm budget and therefore not included as a direct cost in this analysis.

We assumed a 25-year permenancy period and thus economic returns following the Australian Carbon Credit Unit or ACCU Scheme which describes potential carbon income associated with environmental plantings (https://cer.gov.au/schemes/australian-carbon-credit-unit-scheme). To account for the time-value of investment decisions over such long timeframes, discounted cash flow analysis was applied to sum all benefits (carbon payments) and costs into a single net present value (NPV) metric. The NPV of changing from current agricultural land use to carbon land use f at carbon credit price p can be expressed as the difference between the present value of the returns and costs:

$$NPV_{fp} = PV_{fp}^{R} - PV_{fp}^{C} \quad 1.$$

Where PV_{fp}^{R} is the present value of returns to carbon land use f at carbon credit price p and is calculated:

$$PV_{fp}^{R} = \sum_{t=1}^{T} \frac{(p \times Cseq_{ft)}}{(1+r)^{t}} \times 1 - \sum CD \quad 2.$$

Where $Cseq_{ft}$ describes sequestered carbon in each year t over the projects lifetime T , in this case the permenancy period of 25 years. The term CD refers to the discounts applied to ACCUs generated by a project by the scheme and includes the risk of reversal buffer (5%) with corresponding permanency period discount (20%). r is the discount rate applied in discounting future costs and returns.

The term PV_{fp}^{C} in equation 1 is the present value of all costs for carbon land use f:

$$PV_{fp}^{C} = EC_f + \sum_{t=1}^{T} \frac{MC_t + TC_t}{(1+r)^t} \quad 3.$$

Two elements of cost are considered in equation 3. EC_f is the initial establishment cost for carbon land use f, MC_t and TC_t, the maintenance and transaction costs that occur in each year t.

The NPV model (equation 1) was solved iteratively for carbon credit prices p ranging from AUD 1 t CO_2eq.$^{-1}$ to AUD 300 t CO_2eq.$^{-1}$, in AUD 1 increments. The first price returning a positive NPV was considered the break-even price. Carbon prices were treated as deterministic over the project lifetime of 25-years. Results for two specific carbon prices, AUD 38 t CO_2eq.$^{-1}$ and AUD 100 t CO_2eq.$^{-1}$ were also calculated to align with the ACCU prices used for changes in other aspects of the farm system. The lower price was set to reflect Australian prices over the last couple of years[5] while the higher price was set to reflect international carbon markets, such as the European Union market price varying between €60-100[6], equivalent to approx. AUD 100 – 160 (based on an exchange rate of €1=AUD1.62; 14 June 2024).

The results of the NPV model were converted to annual equivilents (AE) for comparison to the grazing enterprises and incorporation into each farms partial budget.

$$AE = \frac{NPV_{fp} \times r}{(1-(1+r)^{-t}} \quad 4.$$

Carbon sequestration from environmental plantings were modelled by FLINTpro provided in the form of total annual cumulative carbon sequestration for each project. Using the total project area, provided exogenously to this modelling, an estimate of sequestration on a per hectare basis was made. Annual incremental sequestration was estimated by differencing the cumulative per ha estimates (Fig. S1).

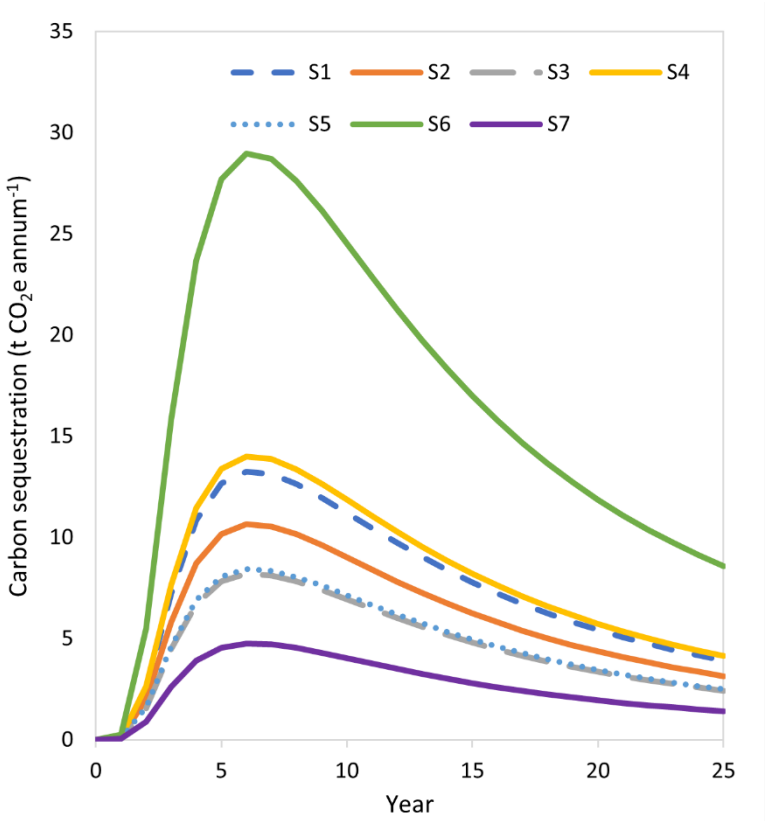

Fig. S1. Annual carbon sequestration for each case study farm from planting in year zero. Colours represent farms, with S1-7 = farms 1 to 7. These data were used in FlintPRO to model annual carbon sequestration in vegetation.

Cost of carbon planting establishment and maintenance were differentiated spatially to account for location attributes influencing these costs. For example, direct seed and mechanical tube stock plantings are unsuitable in areas on steep slopes due to the need for machinery access, in these areas manual tube stock methods are more suitable. Summers *et al*.[7] developed a decision algorithm that attributed the most suitable planting method across the landscape based on the underlying biophysical and geographic variables such as slope and soil type. The result is a spatially differentiated estimates of establishment costs across the agricultural areas of Australia (Fig. S2). These data were updated for inflation using the Consumer Price Index (CPI)[2].

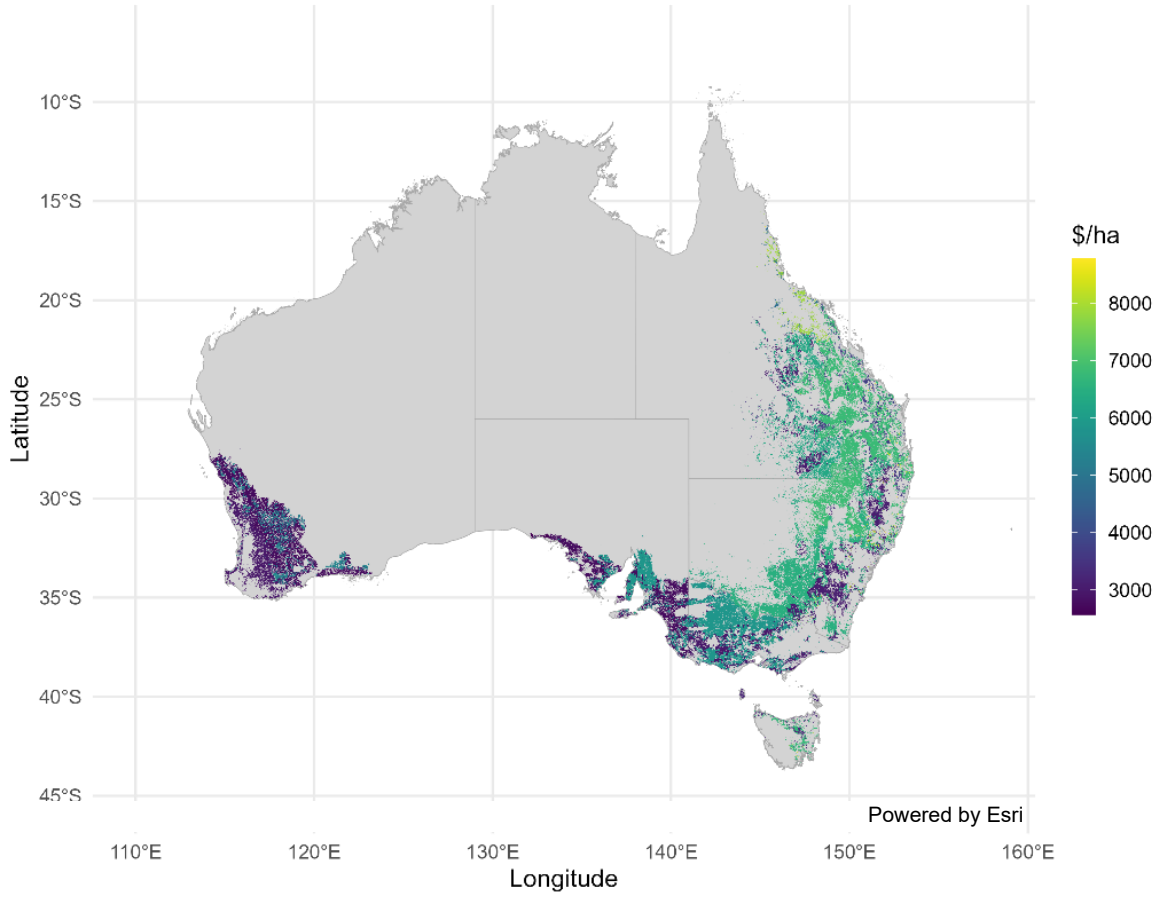

Fig. S2. Mean cost of planting native tree species in 2023 (AUD ha^{-1}). Costs include establishment and maintenance over the expected tree lifetime. Grey regions indicate no data. Data derived from Summers *et al*.[7]

Applying these data to the case study farms, Table S6 indicates the assumed establishment costs included in the economic analysis.

Table S6. Establishment costs for planting native tree species. S1-6 = farm numbers. NSW = New South Wales, SA = South Australia, VIC = Victoria, TAS = Tasmania, WA = Western Australia.

Case study farm (State)	Cost (AUD ha^{-1})
S1 (TAS)	4,209.05
S2 (SA)	2,749.14
S3 (VIC)	2,959.13
S4 (NSW)	3,052.00
S5 (WA)	2,741.00
S6 (VIC)	2,959.00
S7 (SA)	2,959.00
S1 (TAS)	4,209.05
S2 (SA)	2,749.14
S3 (VIC)	2,959.13

Fencing costs are a large variable cost for a carbon planting establishment. Spatial data was collected on the spatial configuration of each property. Priority tree planting areas were

identified with each landholder (Figs. S3 and S4). The priority areas identified were used as the basis for determining a plausible configuration for any tree planting project. This data was used to estimate the total length of fencing (linear metres) that would be required for each property (Table S7). It was assumed that no existing fencing exists in that location and new fencing would need to be constructed. It is clear from Fig. S3 with farm S5 (WA) that some tree plantation configurations are complex, with more complex spatial arrangements were associated with higher fencing costs. These may in reality be simplified; however, this was not able to be determined with the data available. A range of fencing prices were tested ranging from AUD 9 to AUD 13 metre^{-1} with AUD 9 metre^{-1} treated as the most likely and implemented in the study with results shown in Table S7.

Table S7. Fencing distances and total fencing costs associated with planting native tree species on seven case study farms. Data based on 10% of the grazing area removed from grazing and planted to trees. S1-6 = farm numbers. NSW = New South Wales, SA = South Australia, VIC = Victoria, TAS = Tasmania, WA = Western Australia.

Case study farm (State)	Distance (m)	Cost (AUD)
S1 (TAS)	24,014	216,131
S2 (SA)	24,363	219,267
S3 (VIC)	12,373	111,353
S4 (NSW)	1,333	12,000
S5 (WA)	51,126	460,130
S6 (VIC)	18,752	168,767
S7 (SA)	5,899	53,092

Maintenance costs are costs associated with the routine repairs of the project. These include, but are not limited to, fence repair, post planting watering and weed and pest control. Estimates from tree planting projects [8,9] indicate annual maintenance costs in the order of AUD 80 – 100 ha annum^{-1}, with the latter used in this analysis.

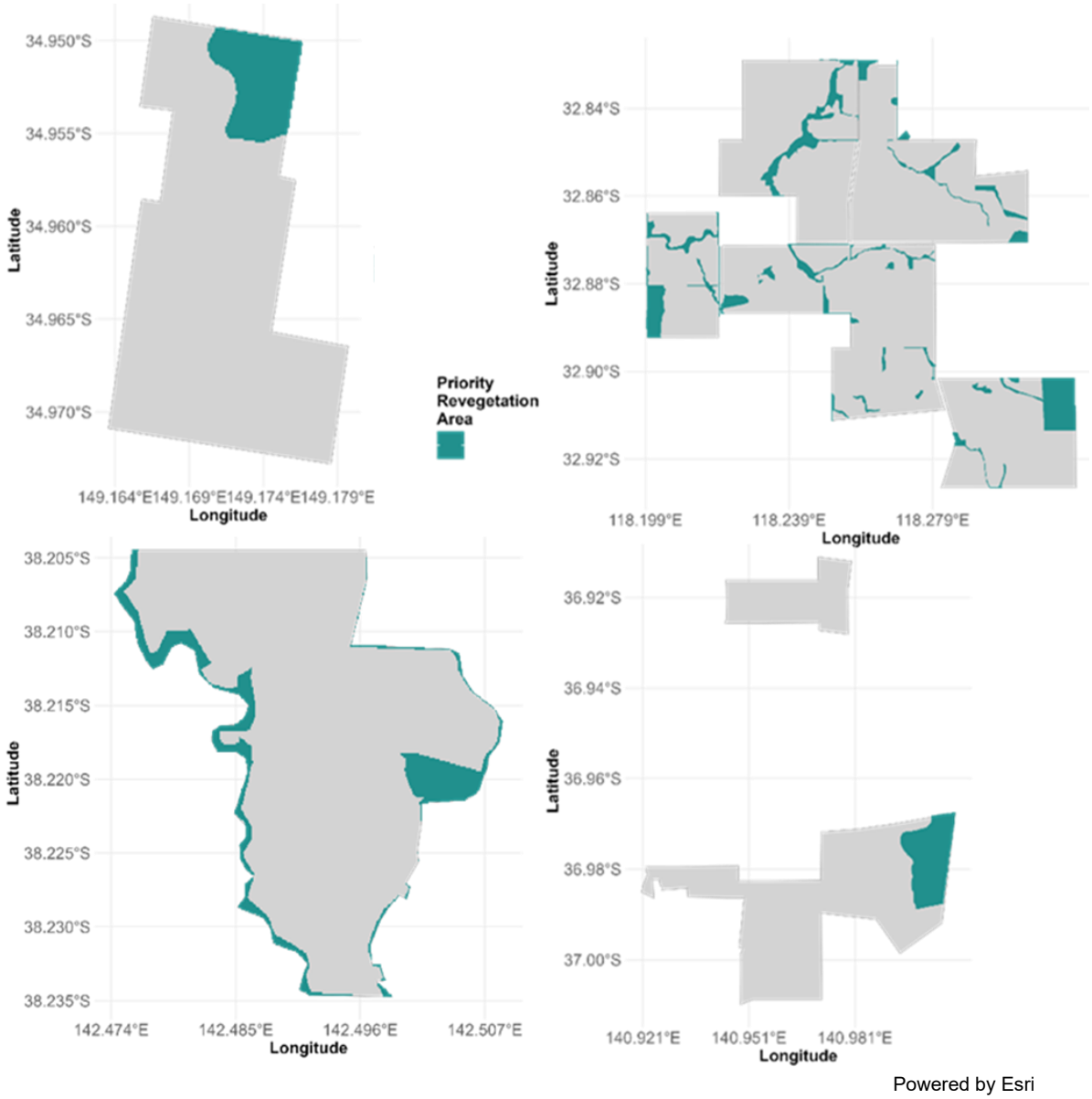

Fig. S3. Priority planting areas for native tree species identified by landholders for case study farms. Abbreviations represent farm names, with farm S4 (NSW) top left image, S5 (WA) top right image, S6 (VIC) bottom left image, S7 (SA) bottom right image. S1-6 = farm number. SA = South Australia, VIC = Victoria, NSW = New South Wales. Data produced in LOOC-B[10].

Fig. S4. Priority planting areas for native tree species identified by landholders for case study farms. Abbreviations represent farm names, with S1 (TAS) top left, S2 (SA) top right, S3 (VIC) bottom. S1-6 = farm numbers. TAS = Tasmania, SA = South Australia, VIC = Victoria. Data produced in LOOC-B[10].

A risk of reversal buffer discount is applied to the number of Australian Carbon Credit Units (ACCUs) issued to sequestration projects. The buffer is designed to protect the ACCU Scheme against potential loss of carbon from risks that cannot be managed by other permanence arrangements. It applies a 5% discount to all ACCUs accrued by a project. The permanence period discount applies to sequestration projects including environmental plantings. For projects electing a permanence period of 25 years, a further discount of 20% is applied to ACCUs accrued by the project[11]. The idea of the permanence period discount is that on average across the portfolio of carbon ACCU projects of this type, it should cover the risks that carbon stored may be returned to the atmosphere at some point over the course of the project.

Ferguson[12] and Manley[13] showed that real discount rates use in woodland valuation in Australia and New Zealand can vary considerably from between 5% to 14%. Ferguson[12] found a discount rate of 7.4% was likely appropriate for deterministic economic analyses. We chose to use a real discount, r, of 7.5%.

Annualised equivalent profits were derived from the above-mentioned analysis. Here we assumed zero brokerage fee and the two carbon prices of AUD 38 t CO_2eq.$^{-1}$ (low ACCU) and AUD 100 t CO_2eq.$^{-1}$ (high ACCU). As these values are on a per hectare basis, we multiplied this

annualised value by the hectares removed from grazing to determine an annualised farm profit/loss (Table S8).

Table S8. Annualised equivalent profit/loss per hectare for each case study farm. Bold results illustrate the two scenarios when planting trees on 10% of the grazing land, as a standalone option (excluding loss of income from reduced stock numbers), was profitable based on the cost profiles and assumptions implemented here. S1-6 = farm numbers. NSW = New South Wales, SA = South Australia, TAS = Tasmania, VIC = Victoria, WA = Western Australia.

Case study farm (State)	Carbon price (AUD tonne CO_2e^{-1})	Annualised equivalent (AUD ha^{-1} $annum^{-1}$)
S1 (TAS)	38	-368
	100	**13**
S2 (SA)	38	-419
	100	-114
S3 (VIC)	38	-403
	100	-167
S4 (NSW)	38	-243
	100	**156**
S5 (WA)	38	-308
	100	-65
S6 (VIC)	38	-201
	100	629
S7 (SA)	30	-309
	100	-172

Unlike ACCU prices, there is no clear market pricing for biodiversity due to the difficulty in quantifying biodiversity values for market purposes[14]. As a result, we implemented Australian Dollar (AUD) prices of AUD 29 (low) and AUD 65 (high) t $CO_2eq.^{-1}$ sequestered, based on indicative prices of Carbon Neutral's Biodiverse Reforestation Carbon Offsets[15]. This, combined with the ACCU price, resulted in a combined low ACCU price of AUD 67 t $CO_2eq.^{-1}$ and a high ACCU price of AUD 165 t $CO_2eq.^{-1}$ for the 10% trees on farm intervention and the farm-specific intervention for S1 (TAS) where we reduced grazing area by 100 ha by fencing off paddocks adjacent to the riverbanks. For S1, we estimated the economic cost of fencing off 4 km of riverbank, based on data from the farmer at AUD 20,000 km^{-1} with a lifespan of 30 years, equivalent to AUD 4,500 $annum^{-1}$ (i.e. 150 metres at AUD 20 $metre^{-1}$ to allow for some maintenance costs per annum). For the same farm, when we modelled fencing off the 4 km of riverbank plus the 9 km of fence line adjacent to native vegetation, at AUD 20,000 km-1 with a lifespan 30 years, this was equivalent to AUD 10,000 $annum^{-1}$ (i.e. 500 metres at AUD 20 $metre^{-1}$ to allow for some maintenance costs per annum). Note that this fencing cost is greater than implemented with the 10% trees on farm intervention to take into account higher-priced wallaby fencing required for the 9 km of boundary fencing and thus replicated for the 100 ha of riverbank area.

3. Impacts of interventions on pasture production and soil organic carbon

We assumed that any intervention resulting in more than 5% change in pasture production relative to the baseline farm system would evoke change in soil organic carbon (Table S9). In the same manner as for the 10% tree planting intervention, we determined a net profit or loss associated with any scenario that resulted in a >5% change in pasture production and

subsequent soil carbon. For any scenario that increased soil carbon, analogous to an Australian soil carbon ACCU scheme project, a 5% risk of reversal buffer discount and 20% permanence period discount were implemented. In addition, we used the same 7.5% discount to estimate an annualised NPV[16]. There is no ACCU scheme that 'penalises' farm practices that results in a decline in SOC. Given the aim of this paper was to review trade-offs associated with interventions, there needed to be a carbon tax placed on lost SOC in the same manner as increased livestock-derived GHG emissions are also taxed. An analysis of the effect of each of the three discount rates mentioned above illustrated that including the 5% reversal buffer and 20% permanence period discount as well as the 7.5% discount rate did not generate a substantial reduction in GM. For example, if SOC declined by 100 t CO_2e annum^{-1}, relative to the baseline farm system, at a carbon price of AUD 38 t CO_2eq.$^{-1}$ and including all three discount rates, the NPV was estimated as a loss of ~ AUD 1,270 annum^{-1}; a value far short of a potential income loss of AUD 3,800 annum^{-1} if we had simply multiplied the loss of carbon by the carbon price. By removing the 5% reversal buffer and 20% permanence period discount in the NVP estimate, losses increased to AUD 1,695 annum^{-1}. This higher cost better reflects the increased carbon tax that should be placed on scenarios that result in lost soil carbon.

Table S9. Soil organic carbon flux (t CO_2eq. ha^{-1} annum^{-1}) simulated using FlintPRO for each 5% change in pasture production relative to the baseline pasture production. Soil organic carbon changes of less than 5% relative to the baseline system were deemed *de minimus*.

	Soil carbon flux (t CO_2eq. ha^{-1} annum^{-1})				
Change in pasture production	**-10%**	**-5%**	**+5%**	**+10%**	**+15%**
S1 (TAS)	-0.54	-0.29	0.34	0.73	1.21
S2 (SA)	-0.68	-0.37	0.43	0.94	1.55
S3 (VIC)	-0.69	-0.37	0.43	0.95	1.57
S4 (NSW)	-0.66	-0.36	0.42	0.91	1.51
S5 (WA)	-0.62	-0.33	0.39	0.85	1.40
S6 (VIC)	-0.74	-0.39	0.46	1.01	1.67
S7 (SA)	-0.82	-0.44	0.51	1.12	1.85

4. Replacing mono-ammonium phosphate with green waste compost (S6)

Case study farm S6 applies 32 tonnes of mono-ammonium phosphate (MAP) fertiliser per annum. This fertiliser was replaced with an organic compost at a rate to match to phosphorus application per hectare. The cost of application was derived from the compost supplier used by the case study farmer (Table S10). The GrassGro fertility scalar was increased by 3% to increase pasture production following commensurate changes observed in peer-reviewed literature[17]. The net change in GHG emissions associated with compost derived from the Australian National Greenhouse Gas Inventory[18,19] was included in SB-GAF (Table S11).

Table S10. Costs for replacing mono-ammonium phosphate (MAP) with green waste compost. The costs were used only for analysis of farm S6.

Baseline	tonnes MAP required per year	32.0
	Cost of fertiliser t^{-1}	AUD 1,450
	Spreading costs $hectare^{-1}$	AUD 0[a]
	Total cost MAP	AUD 46,400
Compost	tonnes compost (wet)	1,760
	AUD $tonne\ compost^{-1}$	AUD 18.25
	Compost cost	AUD 32,120
	Transport product (AUD $tonne\ compost^{-1}$) [b]	AUD 21.64
	Total transport cost	AUD 38,080
	Total cost compost[c]	AUD 70,000
	Spreading cost (AUD $tonne^{-1}$)	AUD 12.50
	Total spreading cost	AUD 22,000
	Total cost of compost	AUD 92,000
Additional nutrients supplied with compost	Potassium fertiliser requirement (kg ha^{-1})	70
	Muriate of Potash (MoP ha^{-1})[d]	
	Hectares applied per annum	440
	Savings in potassium per annum (t MoP)	30.8
	Cost of MoP per annum (AUD $tonne\ fertiliser^{-1}$)[e]	850
	Savings in potassium per annum	AUD 21,180
Intervention cost of compost per annum		AUD 65,820
Cost above that of MAP fertiliser per annum		AUD 19,420

[a] No external cost for spreading MAP as undertaken by case study farmer; [b] Cost per tonne product (AUD 21.50 t^{-1}) plus per km distance (AUD 1.5 km^{-1} and estimated at 160 km return from supplier) supplied by Camperdown Compost; [c] Compost supplier cost was AUD 70,000; [d] While no potassium fertiliser was accounted for in the baseline, a long-term requirement was assumed; [e] https://www.austrade.gov.au/en/news-and-analysis/analysis/farm-food-costs-rise-due-to-higher-energy-prices

Table S11. Greenhouse gas emissions associated with replacing mono-ammonium fertiliser with green waste compost derived from the Australian National GHG Inventory and peer-reviewed literature (see base of table). MAP = mono-ammonium phosphate, GWP = global warming potential.

		MAP	Compost
Direct N_2O	Emission factor (N_2O-N kg N^{-1})	0.002[a]	0.0001[b]
	Conversion factor (elemental N to molecular N)	1.57[a]	1.57
	GWP N_2O	265[a]	265
	Rate of N applied (t)	3.2	17.62
	Total CO_2 (t)	2.67	0.73
Indirect N_2O through volatilisation	Emission factor (NH_3-N kg N^{-1})	0.11[a]	0.033[b]
	Conversion factor (elemental N to molecular N)	1.57[a]	1.57
	GWP N_2O	265[a]	265
	Rate of N applied (t)	3.2	17.62
	Total CO_2 (t)	0.29	0.02
Indirect N_2O through leaching	Emission factor (NO_3-N N applied^{-1})	0.24[a]	0.027[b]
	Emission factor (Gg N_2O-N kg N^{-1})	0.011[a]	0.011[a]
	Conversion factor (elemental N to molecular N)	1.57[a]	1.57[a]
	GWP N_2O	265[a]	265[a]
	Rate of N applied (t)	3.2	17.62
	Total CO_2 (t)	3.52	2.18
Scope 3	Emission factor for Scope 1 at production (t CO_2eq. t product^{-1})	0.7[c]	0.046[d]
	Total product (t)	32	1,232
	Total CO_2 (t)	22.5	56.67
Total emissions (t CO_2eq.)		28.97	59.61
Additional GHG with compost (t CO_2eq.)			30.63

[a] DCCEEW[18]; [b] Nicholson et al.[20]; [c] As per Scope 3 emissions for MAP fertiliser in SB-GAF; [d]DCCEEW[19]

5. Increasing liveweight gain by 10% and 50% for non-replacement animals

The number of days saved by increasing daily liveweight gain (LWG) in the non-replacement animals was determined by subtracting 4 kg (assumed liveweight (LW) at birth) from the sale LW for wether and ewe lambs. This was then divided by the number of days between birth and sale to determine a daily LWG value. We multiplied this by either 1.1 or 1.5 to reflect the 10% and 50% improvement in LWG to determine the new daily LWG values. As the target LW at sale remained the same, this was divided by the new daily LWG value to determine the new days to reach target LW and thus days no longer remaining on farm. Within SB-GAF, we then multiplied the daily CH_4 emission by the number of days saved and the number of lambs sold to determine

the reduction in net enteric CH_4 emissions for the farm system. A condensed version of the estimations for the non-replacement lambs for S1 (TAS) is shown in Table S12. In this example, by improving LWG by 50%, farm GHG emissions were reduced by 32.4 t CO_2e annum^{-1}.

Table S12. Reduction in enteric methane associated with the 50% liveweight gain intervention. This analysis was conducted only for the meat flock on S1 (TAS).

Variable	Wether lambs	Ewe lambs
Date of birth	7 September 2023	7 August 2023
Date of sale for the baseline	15 December 2023	15 December 2023
Days on farm for the baseline	99	99
Liveweight gain (kg)	24.2	22.2
Liveweight gain-baseline (kg day^{-1})	0.24	0.22
Liveweight gain-intervention (kg day^{-1})	0.37	0.34
Days saved	33	33
Methane production (kg CH_4 head^{-1} day^{-1})	0.011	0.011
Methane saved (kg CH_4 head^{-1} day^{-1})	0.36	0.35
Number lambs sold	1,619	1,618
Methane saved (t CO_2eq. stock class^{-1})	16.52	15.86

To achieve 50% improvement in LWG, we determined that lambs would require an additional 4.847 megajoules of metabolisable energy (median value taken from the ME required for 100 g gain in liveweight by immature meat sheep in the Gain tab of CSIRO's SheepExplorer spreadsheet which is the basis of GrassGro estimates; https://grazplan.csiro.au/supporting-programs/) per 100 grams of additional LWG above that of the baseline daily LWG. We valued this additional MJ ME at AUD 0.034 based on an average cost of a blend of grains and forages costing AUD 376.0 t DM^{-1} and supplying 11.3 MJ ME kg DM^{-1}. Thus, each day that the lambs were no longer on farm, the cost per 100 grams of additional LWG day^{-1} was valued at AUD 0.166 head^{-1}. Using the same farm example, where the intervention lambs put on an addition ~ 0.12 kg head^{-1} day^{-1}, relative to their baseline counterparts, and they required supplementation for 66 days between birth and the new sale date, the additional LWG was costed at AUD 41,532 annum^{-1}, with the sums shown in Table S13.

Table S13. Metabolic and economic implications of achieving a 50% improvement in daily liveweight gain (LWG) for S1 (TAS) farm meat flock. ME = metabolisable energy, MJ = megajoules.

Variable	Wether lambs	Ewe lambs
Difference in LWG with intervention (g day^{-1})	122	112
Additional ME required (MJ ME head^{-1} day^{-1})	5.9	5.4
Number of days on farm	66	66
Additional ME required to sale date (MJ ME head^{-1})	390	358
Cost of additional supplement (AUD head^{-1})	13.38	12.28
Total cost for each stock class (AUD)	21,663	19,868

6. Interventions pertaining to feeding Omega-3 oils, fencing off wetlands and boundary fencing

When altering the omega-3 intake of ewes to increase wether lambs for farm S1 (scenario 8), we assumed that the effects of omega-3 supplementation during pregnancy on enteric and manure CH_4 were *de minimus* due to the short feeding period.

When fencing off wetlands and boundary fencing for farm S1 (scenarios 9-12):

- Stocking rate (ewes ha^{-1}) remains the same as the baseline for the wool flock, at 2.8 and 2.7 ewes and wethers ha^{-1}, respectively, and 9.6 ewes ha^{-1} for the meat flock for scenarios 11, 12 and 13, increasing by 0.1 ewes and wethers ha^{-1} for the wool flock and by 0.3 ewes ha^{-1} for the meat flock for scenario 14, and
- Weaning rates remains the same as the baseline for the wool flock, at 0.8 and 0.95 lambs per ewe for the wool and meat flocks, respectively for scenarios 11, 12 and 13, increasing to 0.85 and 1.0 lambs per ewe for scenario 13.

When feeding supplementary lupins to the ewes for higher weaning rates for farm S2, ewes were fed 0.5 kg DM ha^{-1} day^{-1} from 24th October to 7th November. Conception rates within GrassGro were set at 86% singles and 14% twins for the 112% weaning rate scenario (baseline settings), at 78% singles and 22% twins for the 120% weaning rate scenario, and at 57% singles and 43% twins for the 140% weaning rate scenario.

7. Sensitivity analysis

To standardise perturbation across interventions (the purpose of sensitivity analysis being comparison of relative variation), we examined the change in net farm GHG emissions associated with 50% reduction in each intervention. Examples include (i) reducing tree plantings to 5% of grazing land and the remaining 5% of land returns to grazing, (2) with the 100 ha less land and 125 ha more land, reducing these to 50 ha less land and 62.5 ha more land, respectively, while maintaining all other aspects the same (i.e. same weaning and stocking rates as per the 100% intervention), (3) for the fencing weaning rates and fencing stocking rate scenarios, reduce the weaning rate and stocking rate by 50% while maintaining the same grazing are as per the 100% intervention. Fig. S5 shows mean percentage change in net farm GHG emissions. The analysis indicates that planting trees was the most sensitive intervention, followed by the 37% and 18% feed additive interventions. These results can be explained by the fact that the tree planting intervention impacted on both carbon sequestration (through tree growth) and enteric CH_4 (through reduced animal numbers). The sensitivity associated with the 37% and 18% enteric CH_4 inhibitor interventions is also sensible considering that enteric CH_4 often dominates farm GHG emissions.

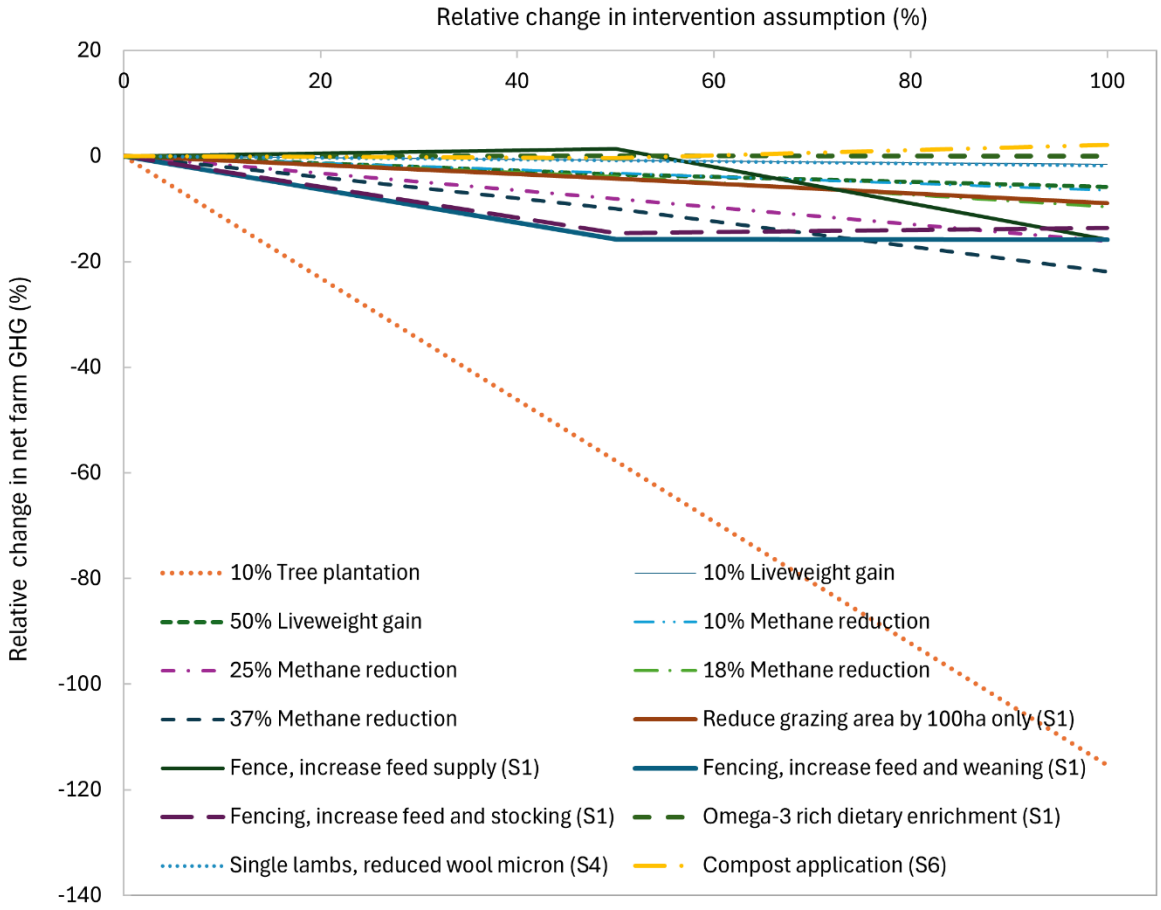

Fig. S5. Percentage change in intervention versus percentage change in net farm GHG emissions. One hundred percent change in intervention corresponds to intervention values in Table 1. For all interventions except those ending in the farm abbreviation (i.e., five interventions at bottom of legend), n = 7; for other interventions, n = 1. CH_4 = methane, ha = hectares, LW = liveweight, S1, S4 and S6 are farm identifications.

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