ETH zürich | sus.lab
Sustainability in Business Lab

Nestlé Good food, Good life

December 2020

Towards climate positive dairy farms

A case study for zero emissions

2020

Contents

I.	Summary	2
II.	Methodology	9
1.	Case farms and abatement lever selection	10
2.	Modelling	22
III.	Results	33
IV.	Outlook	39

Executive Summary | Based on a case study of three farms with Nestlé, dairy farm emissions can be reduced significantly with current technologies at low costs

Goal: Identify the best abatement solutions for dairy farms at Nestlé based on abatement potential and cost

1 Relevance	2 Methodology	3 Outcome	4 Solution highlight	5 Outlook
On-farm **dairy emissions are a large hard-to-abate GHG source** and there are large abatement opportunities	Abatement potential and cost were determined for **8 levers at 3 farm archetypes**	**Emissions** could be **reduced between 30% and 68%,** of which a significant part at **negative or low costs**	Three solutions can be implemented at negative costs: **breeding program, heat abatement and silvopasture**	Large low-cost reductions can be achieved now, **if financing options and education are provided**

Relevance | The project focussed on on-farm dairy emissions because they are a large hard-to-abate GHG source and offer large opportunities

Dairy is a large emitter and consumption will continue to rise

- Dairy is responsible for 2.7% of global anthropogenic GHG emissions[1]
- Dairy consumptions is expected to rise with 17% by 2028[2]
- 96% of adults get essential nutrients from dairy products[3]

Report Says Top 13 Dairy Companies Have As Many Emissions United Kingdom
Forbes

Majority of dairy emissions occur before farm gate and are inherent to having cows [4]

Enteric

54%

CH_4 N_2O

- Feed is digested by microbes in the rumen, which produces CH_4
- Cows belch CH_4

Feed

27%

N_2O NH_3 NO_3

- From crops and grazing land
- Denitrification in soil causes N_2O
- Indirect emissions from NH_3 and NO_3

Manure

10%

NH_3 CH_4 N_2O

- Strongly dependent on manure system
- Indirect N_2O emissions from NH_3
- CH_4 under anaerobic conditions

Energy

2%

CO_2

- From electricity or fuel-driven machinery

Downstream processes **7%**

Emissions are hard to abate, but dairy provides a large opportunity

- Emissions are from complex biological processes
- Large differences between regions and farms require different solutions
- But, soil carbon sequestration could offset the other emissions
- And the first carbon credits for cow emissions have been established

Burping Cows Get the Green Light to Join Carbon-Offset Market
Bloomberg

Climate Solutions
Turning manure into money
Farmers and utilities are burning methane for energy — and curtailing a powerful greenhouse gas in the process
The Washington Post

1) FAO (2010)
2) International Dairy Federation (2016)
3) CISL (2015)
4) FAO and GDP (2018)

Method | Abatement potential and cost were determined for 8 levers at 3 farms, through literature review, expert interviews and modelling

Herd and health	Feed composition[1]	Grazing land
Manure management	Energy	Waste

	Farm 1 (AS)	Farm 2 (SA)	Farm 3 (LA)
Herd size	10	75	3000
Region and climate	Asia Tropical	South America Tropical	Latin America Temperate
Productivity (kg FPCM /cow)[2]	4500	4200	7900
Emission intensity (kg CO_2e /kg FPCM)[2]	1.56	1.50	2.23
Lot type	Freestall No grazing	Partial-confinement Grazing	Freestall No grazing
Manure management	Anaerobic digester	Daily spread	Uncovered anaerobic lagoon

Literature review

6 abatement categories

Expert interviews

8 abatement levers

Modelling

Abatement potential and cost for 3 farms

1. Breeding program
2. Heat abatement
3. Bovaer[3]
4. Feed certification
5. Silvopasture
6. Spikey[4]
7. Anaerobic digester
8. Solar panels

1) Levers related to crop growing were excluded from the study
2) FPCM = Fat Protein Corrected Milk, CO_2e based on GWP100
3) Bovaer is a methanogen inhibitor, with 3-NOP as active ingredient
4) Spikey identifies and sprays nitrification inhibitor on urine patches

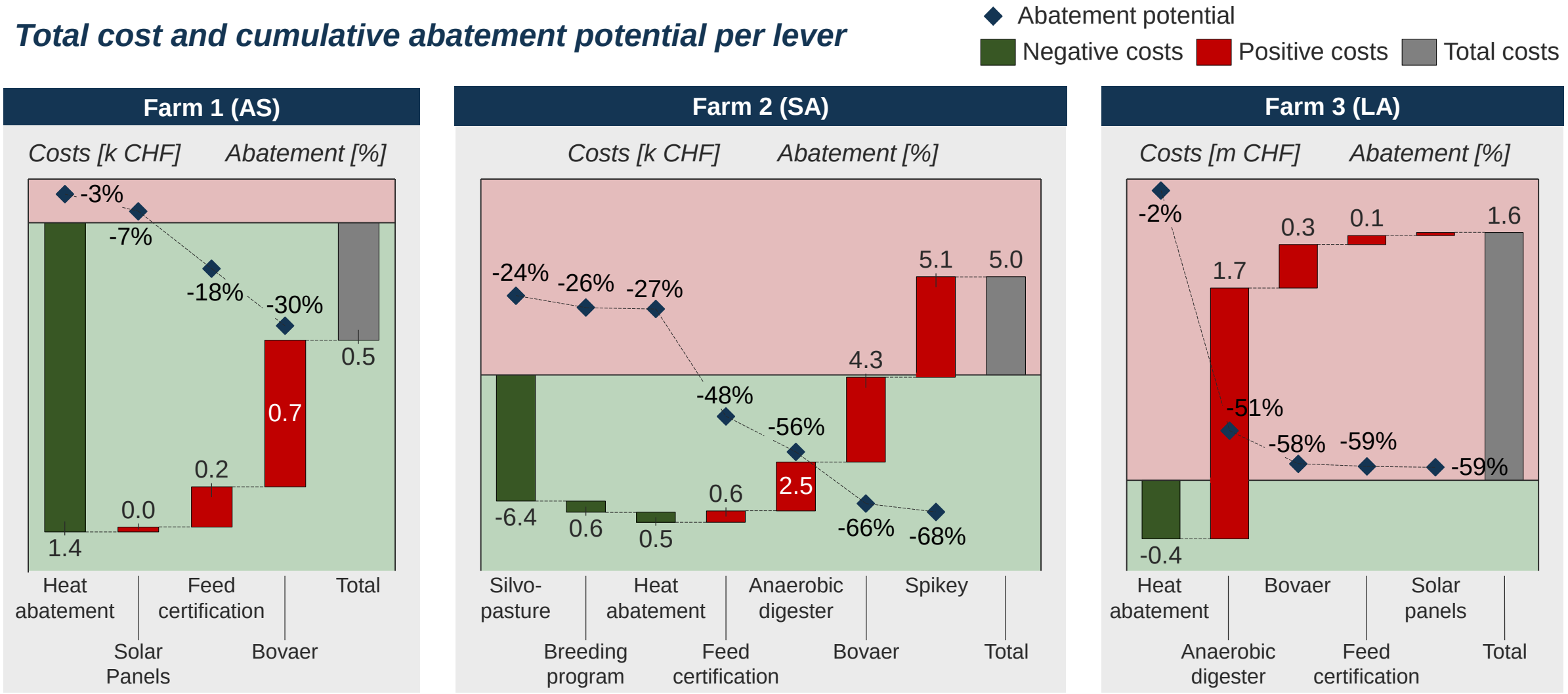
Outcome | Emissions could be reduced between 30 and 68%, of which significant reductions achieved at negative or low costs

Cost and emission intensity of a liter of milk at different abatement costs

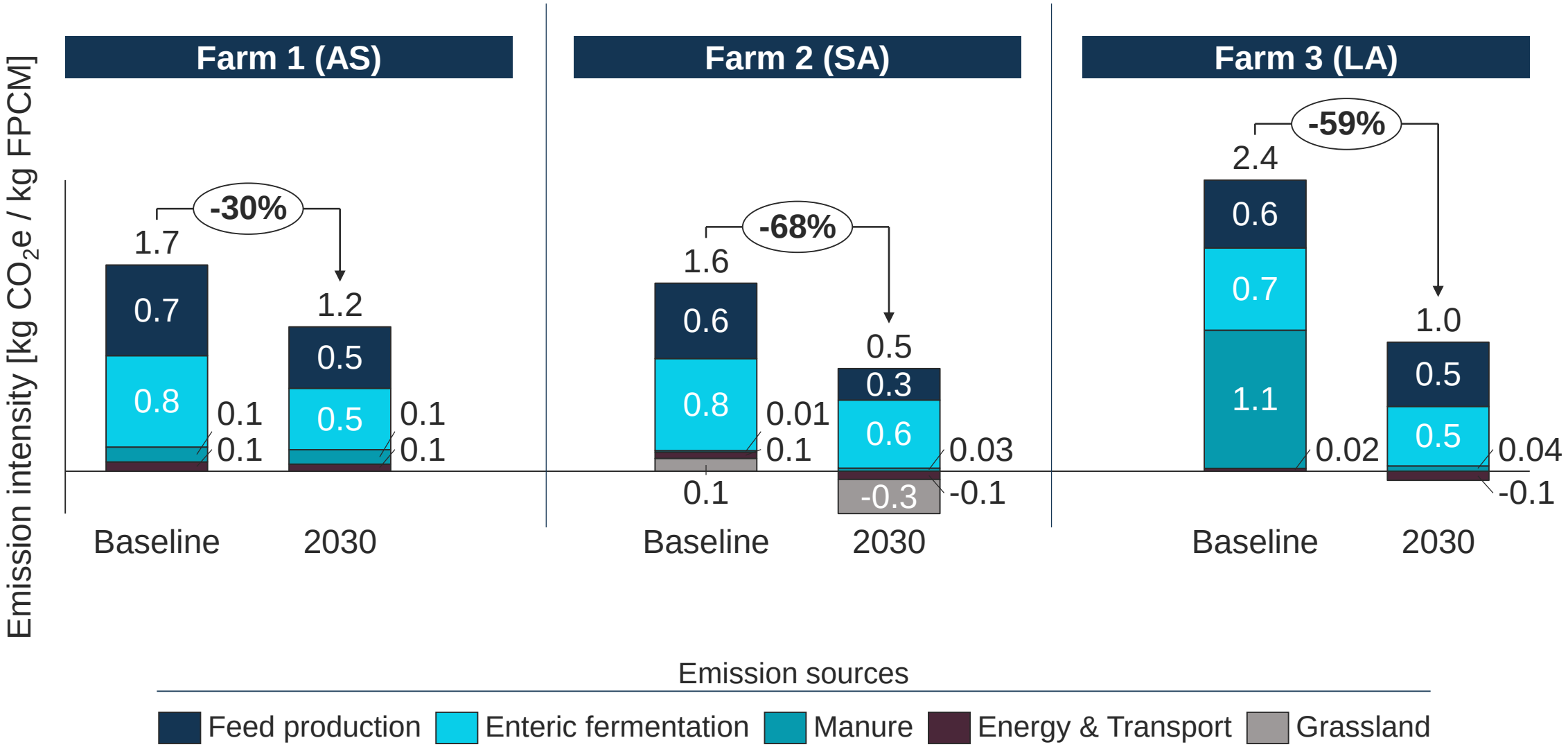
	No levers	<20 CHF/tCO2e		<100 CHF/tCO2e		All levers	
Farm 1 (AS)	1L, 0.400 CHF, CO_2 1.70	• Heat abatement • Solar panels	1L, 0.376 CHF, CO_2 -7%	• Feed certification • Bovaer	1L, 0.389 CHF, CO_2 -30%		
Farm 2 (SA)	1L, 0.400 CHF, CO_2 1.55	• Silvopasture • Breeding program • Heat abatement • Feed certification	1L, 0.379 CHF, CO_2 -48%	• Anaerobic digester • Bovaer	1L, 0.400 CHF, CO_2 -67%	• Spikey	1L, 0.415 CHF, CO_2 -68%
Farm 3 (LA)	1L, 0.400 CHF, CO_2 2.40	• Heat abatement	1L, 0.384 CHF, CO_2 -2%	• Anaerobic digester • Bovaer	1L, 0.463 CHF, CO_2 -58%	• Certified feed • Solar panels	1L, 0.466 CHF, CO_2 -59%

Results | Profit from negative cost measures can be used to pay for more costly measures, resulting in a larger reduction at no cost

Total cost and cumulative abatement potential per lever



Results | If all levers are implemented, enteric fermentation and feed production remain the largest sources of emissions



Solution highlights | Three solutions can be implemented at negative costs: breeding program, heat abatement and silvopasture

Breeding program[1]

CO_2 -2.9%

CHF -0.004 CHF / kg FPCM[3]

- Goal of breeding programme is that **each generation of cows is better than the last**, based on a number of characteristics (e.g. fertility, yield)
- Which **characteristics to focus on is farm-specific** and can be determined with a breeding specialist
- In the future, breeding directly for lower GHG emissions might be possible

Heat abatement

CO_2 -0.7% to -5.1%

CHF -0.002 to -0.032 CHF / kg FPCM[3]

- Cows under heat stress produce less milk and are more receptive to health problems
- Level of heat stress depends on the climate and the cow breed, but **more cows experience cow stress than is commonly thought**
- Heat abatement should also be considered for animal welfare
- **Heat stress can be mitigated with simple systems, like a sprinkler and fan system**

Silvopasture[2]

CO_2 -24%

CHF -0.021 CHF / kg FPCM[3]

- In silvopasture, **trees are incorporated in the pasture**, allowing for carbon sequestration in the trees and shade for the cows
- **Different silvopasture options exist**, from simpler options such as using trees as fencing to using trees as income opportunity, which requires a large management change
- **Costs and abatement potential depend on the silvopastoral system** and trees that are used

1) Already implemented at farms I and III, thus only modelled for II
2) Only modelled for farm II, as farms I and II have no grazing
3) Cost price of milk: ~0.40 CHF / kg FPCM
FPCM = Fat Protein Corrected Milk

Outlook | Although there is a lot of room for further innovation, large low-cost reductions can be achieved now, if financing options and education are provided

Large reductions can be achieved now at low or negative costs

- All farms in the model showed **significant reduction potential**, between 30 and 68%
- On average, larger reductions will be possible as many farms have a higher footprint than the case farms
- The **technology to achieve these reductions is proven and available**
- If cost savings are used to finance more expensive levers, emissions reductions between 2 and 66% could be achieved while being more profitable
- **All on-farm emissions need to be addressed** to reach net zero**,** so there is low risk for focussing on the wrong lever

Financing and education are key for successful implementation

- Even when a lever results in cost savings, **farmers need support for investments**
- Large companies have more favourable financing options and can help farmers with different financing options suitable to the farmer and the abatement lever
- Strong incentives will be needed for levers that remain costly
- **Education or continuous support are necessary for effective implementation**
- Solutions need to be found to finance the emission reductions that cannot be accounted for by the company, e.g. **abated emissions allocated to meat**

More data can create more insights and innovation is happening fast

- **More data collection will help** improve the various emission- and cost models that are used and validate them for different countries and farms
- Data on successful implementation of levers will pave the way for further acceptance and implementation
- **New promising levers are still emerging**, such as breeding for lower emissions or including emissions in the cost-nutrition optimization of feed
- More data will **enable the inclusion of more levers**, most noteworthy related to **health and nutrition,** which both have a significant impact on emissions

Contents

I.	Summary	2
II.	Methodology	9
1.	Case farms and abatement lever selection	10
2.	Modelling	22
III.	Results	33
IV.	Outlook	39

Contents

I.	Summary	2
II.	Methodology	9
1.	Case farms and abatement lever selection	10
2.	Modelling	22
III.	Results	33
IV.	Outlook	39

Cases | 3 farms were chosen within archetypes to represent a wide variety in farms

Selection process

Archetypes

- Nestlé has defined farm archetypes within each market
- Each archetype has a distinctive farm set-up in a specific region

Variety

- 3 archetypes were chosen for the project that differ in location, size and set-up

Farms

- 1 farm was chosen per archetype for which data was available in the Cool Farm Tool

Set-up of the chosen farms

	Farm 1 (AS)	Farm 2 (SA)	Farm 3 (LA)
Herd size (dairy cows)	10	75	3000
Region and climate	Asia Tropical	South America Tropical	Latin America Temperate
Productivity (kg FPCM /cow)[2]	4500	4200	7900
Emission intensity (kg CO_2e /kg FPCM)[2]	1.56	1.50	2.23
Lot type	Freestall No grazing	Partial-confinement Grazing	Freestall No grazing
Manure management	Anaerobic digester	Daily spread	Uncovered anaerobic lagoon

Note: Although the farms represent a larger group of farms, they do not represent all farms, nor are they the most common farm types globally

Levers | Mitigation options were collected through literature review and evaluated on five criteria, based on literature and expert interviews

Most abatement options came from four literature reviews[1]

- Enteric methane
  Hristov et al. (2013a)
- Animal management
  Hristov et al. (2013b)
- Manure management
  Montes et al. (2013)
- Energy and waste
  Eory et al. (2015)

Promising options were evaluated with additional literature and 10 expert interviews

A mitigation option was included if it fulfilled five criteria

Reduction
- Scientific consensus on reduction potential

Safe
- Safe to implement for cow and human

Ready
- Available for commercial implementation in 2021

Case
- Suitable for case farms
- Not yet implemented at case farms

Data
- Sufficient data available for modelling

Modelled

1) Options that were marked as ‘not recommended’ by the authors were not considered

Levers | Mitigation options were divided in 6 categories with 17 subcategories

Herd and health

- Breeding management
- Improved productive life
- Healthcare
- Stress mitigation

Manure management

- Storage and handling
- Application

Feed composition

- Feed rationing
- Methanogen inhibitors
- Emission intensity of feed

Energy

- Generation
- Utilization

Grazing land

- Pasture management
- Grazing management
- Other land use
- Excretion on pasture

Waste

- Milk waste
- Other waste

Levers | The next slides show, per category, for each lever that was considered which criteria was fulfilled and why it was excluded from modelling

Category	Lever	Criteria not fulfilled	Explanation
Category I	Lever I	Criteria that was not fulfilled by lever	Explanation for criteria unfulfilled
	Lever II		

Reduction
Safe
Ready
Case
Data

Levers | Herd and health (1/2)

Category	Lever		Criteria not fulfilled	Explanation
Breeding management	Optimal type of breed		Case	Already implemented at case farms
	Selection for	Residual feed intake Low enteric emissions	Ready	Requires more research (GRA & SAI, 2015; Hristov et al., 2013b)
		Reduced inbreeding	Data	No data available on extent to which inbreeding occurred at case farms
	Assisted reproductive technologies	Artificial insemination	Case	Already implemented at case farms
		Sexed semen	Case	Not as important when meat from calves is used for consumption, which is done on the case farms (Hristov et al., 2013b)
		Heat detection	Data	No data on fertility or current forms of heat detection available
		Hormonal synchronization Embryo transfer	Data	Not suitable as general breeding strategy, but only for specific cases (De Vries et al., 2008) No data available on suitability for case farms

Levers | Herd and health (2/2)

Category	Lever	Criteria not fulfilled	Explanation
Improved productive life	Recombinant bovine somatotropin (rbST)	Safe	Use of rbST can lead to “severe and unnecessary pain, suffering and distress” for the cattle (Scientific Committee on Animal Health and Animal Welfare of the European Union, 1999)
	Early puberty Early weaning Reduce seasonality	Data	No data available on the breeding specifics
	Shorten dry period	Reduction	Uncertain if advantages (e.g. increased milk production before calving and improved energy balance in early location) outweigh disadvantages (e.g. reduced milk production post-calving (Van Knegsel et al., 2014) Long-term study proving profitability required (Van Knegsel et al., 2014)
Healthcare	Animal health Reduced animal mortality Vaccination Reduction of disease as a stressor Subclinical mastitis Disease prevention	Data	No health data available
Stress mitigation	Stress from handling and transport	Data	No data available on amount or manner of handling or transport

Levers | Feed

Category	Lever	Criteria not fulfilled	Explanation
Feed rationing	Tannins, dietary lipids, and concentrate Processing the feed Changing feeding method Precision feeding Reduce dietary protein Increased DMI during the periparturient period	Data	Insufficient data to quantify potential abatement due to complexity of nutrition (Expert interviews)
Methanogen inhibitors	Mootral	Reduction	Trials have shown inconsistent results (Expert interviews) Garlic and citrus might affect milk and meat quality (Expert interviews)
	Agolin Alltech	Data	Claims reduction through increased performance Cannot be modelled without evaluating nutrition as a whole
	Asparagopsis (red algae)	Ready / Safe	Still in trial stage, not ready for large scale implementation Might contain a carcinogen which has not yet been proven safe for cow or human consumption (Expert interviews)
	Nitrates	Safe / case	Toxicity risk for cows dependent on levels of nitrates, not suitable for the case farms (Expert interviews)
	Direct-fed microbials	Ready	Locus Fermentation Solutions (2020) stated that they found non-GMO microbials that can reduce emissions by 78%, but still in initial lab trial stage

Levers | Grazing land

Category	Lever	Criteria not fulfilled	Explanation
Pasture management	Improving forage quality	Data	No data on type of forage grown
	Changing soil nitrogen balance	Data	No data on nitrogen balance in the soil
	Carbon sequestration in soil	Reduction	No scientific consensus on the potential for sequestration in soil pasture unless soil is degraded (Expert interviews)
Grazing management	Timing of grazing Grazing intensity	Data	No data available on the timing or intensity of the grazing
Other land use	Negative emission solutions	Data	Unused land could be used for negative emissions, e.g. with forestation No data available on the existence of unused land on the farm
Excretion on pasture	Dicyandiamide (DCD)	Safe	Not modelled due to controversy and regional bans because traces of DCD were found in milk (New Zealand Ministry for Primary Industries, 2013)

Mitigation options | Manure management

Category	Lever		Criteria not fulfilled	Explanation
Storage and handling	Manure system in housing Biofiltration system		Data	No data on type of housing at case farms
	MMS	Solids separation Aeration Manure acidification Nitrification inhibitor	Other	Not modelled because it would interfere with the use of an anaerobic digester as mitigation option
	Enhancing biogas		Case	Only economically feasible for larger farms (Expert interview)
	Decrease storage temperature Decrease storage time Cover storage Composting Sealed storage with flame Aeration during liquid manure storage		Other	Not modelled because it would interfere with the anaerobic digester mitigation option
Application	Injection Timing		Data	No data available on how much manure was used as fertilizer on the land or on what methods were used

Mitigation options | Energy

Category	Lever	Criteria not fulfilled	Explanation
Generation	Solar water heating Air-source heat pumps	Data	No data available on heating
	Small-scale hydro-electric power Ground-source Wind power	Case	Not possible at case farms
Utilization	Increased fuel efficiency	Data	No data available on the energy use of different machinery
	Increased heating efficiency Efficient cooling of milk Efficient ventilation and cooling Efficient lighting	Data	No data available on the energy use of different machinery

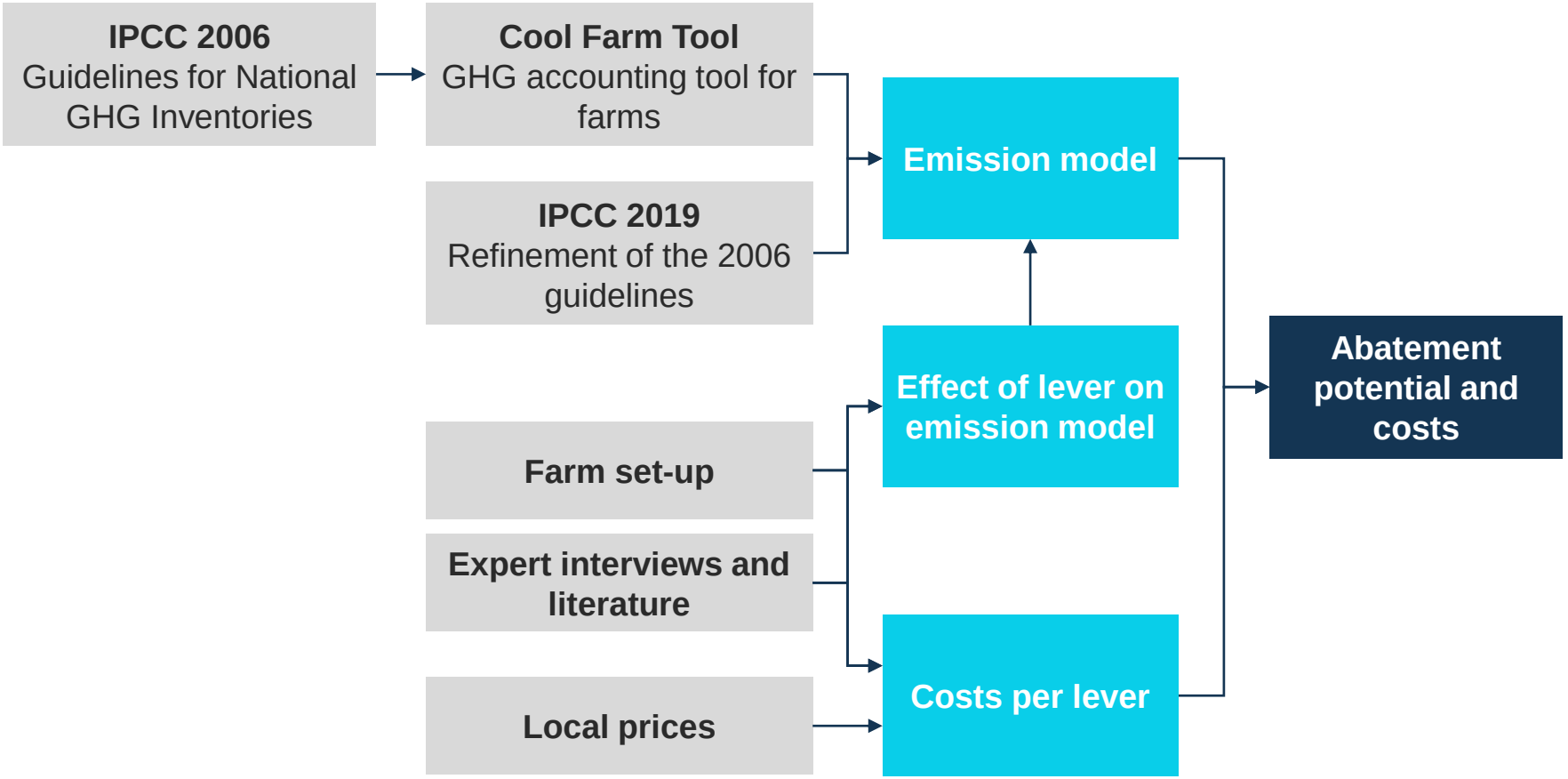
Mitigation options | Waste

Category	Lever	Criteria not fulfilled	Explanation
Milk waste	Reduce waste during storage	Data	No data available on milk waste in the Cool Farm Tool
Feed waste	Precision feeding	Data	No data available on waste

Contents

I.	Summary	2
II.	Methodology	9
1.	Case farms and abatement lever selection	10
2.	Modelling	22
III.	Results	33
IV.	Outlook	39

Model | The emission model is based on the Cool Farm Tool and expanded to include abatement levers and costs



Source: Cool Farm Alliance (2019), IPCC (2006), IPCC (2019)

Abatement potential

- GHG included are CO_2, NO_2 and CH_4
- Use of GWP_{100} to express all GHG in CO_2e
- Emissions allocated to dairy or meat, only dairy emissions considered in model
- Allocation factor based on cows sold at farm, resulting in allocation factors between 75-90%

Abatement costs

- Investment costs considered with depreciation rate
- No distinction in final cost between investment and operational costs
- No discount rate used
- Due to the emission allocation factor, the positive abatement costs are 10-25% higher than if all farm emissions were considered

8 levers fulfilled all criteria and were modelled: breeding program, heat abatement, Bovaer, feed certification, silvopasture, spikey, anaerobic digester and solar panels

Herd and health

1. Breeding program
2. Heat abatement

Feed composition

3. Bovaer
4. Feed certification

Grazing land

5. Silvopasture
6. Spikey

Manure management

7. Anaerobic digester

Energy

8. Solar panels

Waste

Lever 1 – Breeding Program | Breeding to increase yield

Explanation

- Goal is to increase economic breeding index (EBI) of each generation of cows
- EBI is based on seven traits which determine economic value of cow: milk production, fertility, calving performance, beef carcass, cow maintenance, cow management, and health [1]
- Breeding programme can focus on any of the traits, but improving some might result in a reduction in others

Next steps and considerations

- Traits to focus on depend on the farm
- Breeding program should be developed with expert
- Data collection is important for a successful program

Modelling assumptions

General

- EBI changes:
  - Increase in milk yield
  - Decrease in fertility

Mitigation

- Annual yield increase: 41 kg /cow [2]
- Decrease in fertility: 1% / 5% yield increase [3]
- Decrease in fertility leads to more open days and thus a decrease in calves born and decrease in lactation days [3]
- Changes to model (year 10):
  - ΔYield (kg /cow /day) 0.3
  - ΔCow milk; dry -0.5; 0.5
  - ΔMeat (kg) -71

Cost

- Artificial insemination already used and paid for
- Consult breeding specialist: 700 CHF /yr [4]

1) Berry et al. (2007)
2) Canaza-Cayo et al. (2016)
3) Expert opinion
4) Based on salary US breeding specialist

Lever 2 – Heat abatement | Installing fans and sprinklers

Explanation

- Cows experience heat stress when it is too hot and/or humid
- Installing a cooling system can reduce the heat stress, not only increasing yield, but also animal welfare

Next steps and considerations

- Heat abatement equipment is sometimes installed or used wrongly, negating the positive effects
- Installing automated equipment can reduce this risk

Modelling assumptions

Mitigation

- Calculate Temperature Humidity Index (THI)[1] based on local monthly temperature and humidity data
- Breed specific threshold for heat stress
- Heat stress decreases milk yield and dry matter intake
- Other advantages also reported (increased fertility, reduced death rate), but assumed to be negligible
- Additional emissions from increase in electricity

Cost	Farm 1	Farm 2	Farm 3
Cost of equipment (CHF)	145	1580	98k
Operating cost (CHF /yr)	330	1900	109k

1) St Pierre et al. (2003)

Lever 3 – Bovaer | Supply Bovaer to all dairy cows

Explanation

- Bovaer is a methanogen inhibitor produced by DSM
- The active ingredient in Bovaer is 3-nitrooxypropanol (3-NOP)
- 3-NOP oxidizes the enzyme that is responsible for the reduction to CH_4 in the last step of the methanogenesis in the rumen, blocking the production of CH_4
- Bovaer can be administered through regular feed ration

Next steps and considerations

- Implementation has to wait for DSM's decision to go to market
- Current expected reductions are 30%, but a trial in which a higher dose of 3-NOP was given, showed reductions up to 80% showing potential for further reductions
- Bovaer is currently only registered for dairy cows, but registration for calves and heifers is being prepared
- Footprint of 3-NOP production could drop to 35 kg CO_2e/kg 3-NOP with further optimization
- Some trials seem to show an efficiency improvement of 3% ECM/DMI[1], but additional validation is required

Modelling assumptions

General

- Bovaer will only be supplied to dairy cows
- Ready for market in 2021

Mitigation

- Methane conversion factor is decreased with 30%
- Production footprint of 3-NOP: 52 kg CO_2e /kg 3-NOP

Cost

- No capital expenditure required
- Only cost is Bovaer which will be per head per year
- Cost is based on a base-price of 60 CHF/tCO_2e avoided, as communicated by DSM

1) ECM = Energy corrected milk, DMI = Dry matter intake

Lever 4 – Feed certification | Reduce land-use change emissions by purchasing certified feed

Explanation

- Emissions from land-use change (LUC) are significant contributors to emissions from feed production
- When feed is certified produced without LUC, these emissions are not considered

Next steps and considerations

- If the feed (source) is not changed, but only certified, there is no actual emission reduction
- This lever is likely limited by the availability of certified feed

Modelling assumptions

General

- Availability of the feed is not considered
- LUC emissions are included in the feed database from the model

Mitigation

- All land-use emissions can be mitigated

Cost

- Feed is based on the cost of soy
- Additional cost of certification is 1% of price[1]

1) Merité (2018), as cited in Culliney (2018

Lever 5 – Silvopasture | Planting Eucalyptus trees on grazing land

Explanation

- Silvopasture is the practice of planting trees on grazing land
- There are different types of silvopastoral management systems, all with different advantages and disadvantages (Cubbage et al., 2012)

Next steps and considerations

- Revenue stream only after 11 years, long pay-back period
- Modelled system requires systemic change in farm management, farmer might not be willing
- Other silvopastoral systems are easier to manage, e.g. by using trees as fencing, but might be financially less attractive

Modelling assumptions

General

- System where 60% of wood is sold for energy, 40% for timber
- Grazing area: 50 ha
- Implementation rate: 80%
- Number of trees (spacing 10x4): 250 trees /ha
- Type of tree Hybrid Eucalyptus tree
- Rotation period: 11 years

Mitigation

- Emission reduction due to reduction in natural gas from energy wood and sequestration in timber wood
- Sequestration only based on carbon in trees
- Other reported advantages (e.g. increase in milk yield), assumed to be negligible

Cost

- Planting costs: 270 CHF /ha
- Maintenance costs: 110 CHF /ha /yr
- Revenue from wood: 9050 CHF /ha /11yr

Lever 6 – Spikey | Reducing emissions from excretion by spraying urine patches with a nitrification inhibitor

Explanation

- Spikey is a machine that can be added on to a tractor or small robotic tow vehicle and is used on the paddock after cows have grazed in a rotational grazing system and has two functions:
  - It detects urine patches and sprays it with a nitrification inhibitor (Nitrostop), thus reducing N_2O emisions
  - It detects where grazing land requires growth hormones and trace elements and applies this, thus increasing grass dry matter between 25-50% and reducing the need for fertilizer up to 30%
- Spikey with the use of plant growth hormones and trace elements is available from 2021 and Nitrostop is expected to be available for widespread implementation in 2023[1]

Next steps and considerations

- Economically more attractive in a system that uses fertilizer and where grass is a constraining factor, which is common in many farm systems
- In economic analysis conducted by Spikey on farms in New Zealand, it was profitable due to cost savings from dry matter and fertilizer

Modelling assumptions

Mitigation

- Spikey used on the paddock that heifers and dairy cows just grazed on
- Reduction of N_2O emissions from excretion 30%
- Stocking density of paddock 130 m^2/cow
- Additional emissions from diesel for tractor: 1.25 L/ha

Cost

- Purchasing Spikey: 19’115 CHF
- Maintenance Spikey: 1500 CHF /yr
- Purchase of NitroStop: 30 CHF /yr /head
- Cost of fuel 480 CHF /yr
- No savings from fertilizer use, as no fertilizer is used
- No savings from more grass available, as this is not known to be a limiting factor of dry matter intake

1) Even though Nitrostop is only available from 2023, this functionality was already included in the model

Lever 7 – Anaerobic digester | Digester as sole manure management, using the biogas for energy, and the digestate as fertilizer

Explanation

- In an anaerobic digester, organic matter from the manure is broken down and biogas is produced
- Biogas can be used as a fuel or processed further into natural gas or electricity
- Digester also outputs digestate, which can be used as organic fertilizer

Next steps and considerations

- Managing manure is a labour intensive task and many implemented digesters are no longer operational because of lack of maintenance
- Companies exist that take over manure management, investigate if these initiatives exist in these areas
  - Digester on farm, but external party manages manure
  - Covered lagoon digester, pipe to larger facility where they clean the biogas

Modelling assumptions

General

- Set-up of manure management system:
  - No pre-storage
  - High-quality digester with average quality storage
  - Heat retention time of 30 days[1]
  - Coverage of the digestate, fraction of nitrogen loss: 0.1

Mitigation

- Emission reduction due to less CH_4 and N_2O emissions from manure management, based on IPCC (2019)
- Emission reduction from using biogas instead of natural gas
- Conversion factor from volatile solid to biogas: 0.27 m^3/kg

Cost

- Cost of digester: 10’000 CHF
- Maintenance: 500 CHF /year
- Operation: 500 CHF /year
- Cost reduction due to less natural gas bought: -0.01 CHF/kWh
- Cost reduction in fertilization, due to higher N in manure: -0.19 CHF/ kg fertilizer

1) Montoro et al. (2017)

Lever 8 – PV | Using solar panels to generate electricity to cover usage

Explanation

- Solar panels (PV) reduce emissions from electricity use when emission intensity (EI) of PV is lower than the EI of the grid

Next steps and considerations

- In countries with very low emission intensity, installing solar panels does not provide an emission reduction as the emission intensity of the grid is lower than that of solar panels
- Profitability of this lever strongly depends on local policies

Modelling assumptions

General

- Solar panels placed on roof, all roof assumed to be suitable
- Amount set to meet electricity use (incl. additional electricity from heat abatement), limited by roof area
- Case countries have net-metering system

Mitigation

- Specific photovoltaic power output based on location
- Kilowatt peak: 0.1 kWp /m^2

Cost

- Cost of installation: 1200 - 2500 CHF /kW
- Savings from less electricity from the grid

Contents

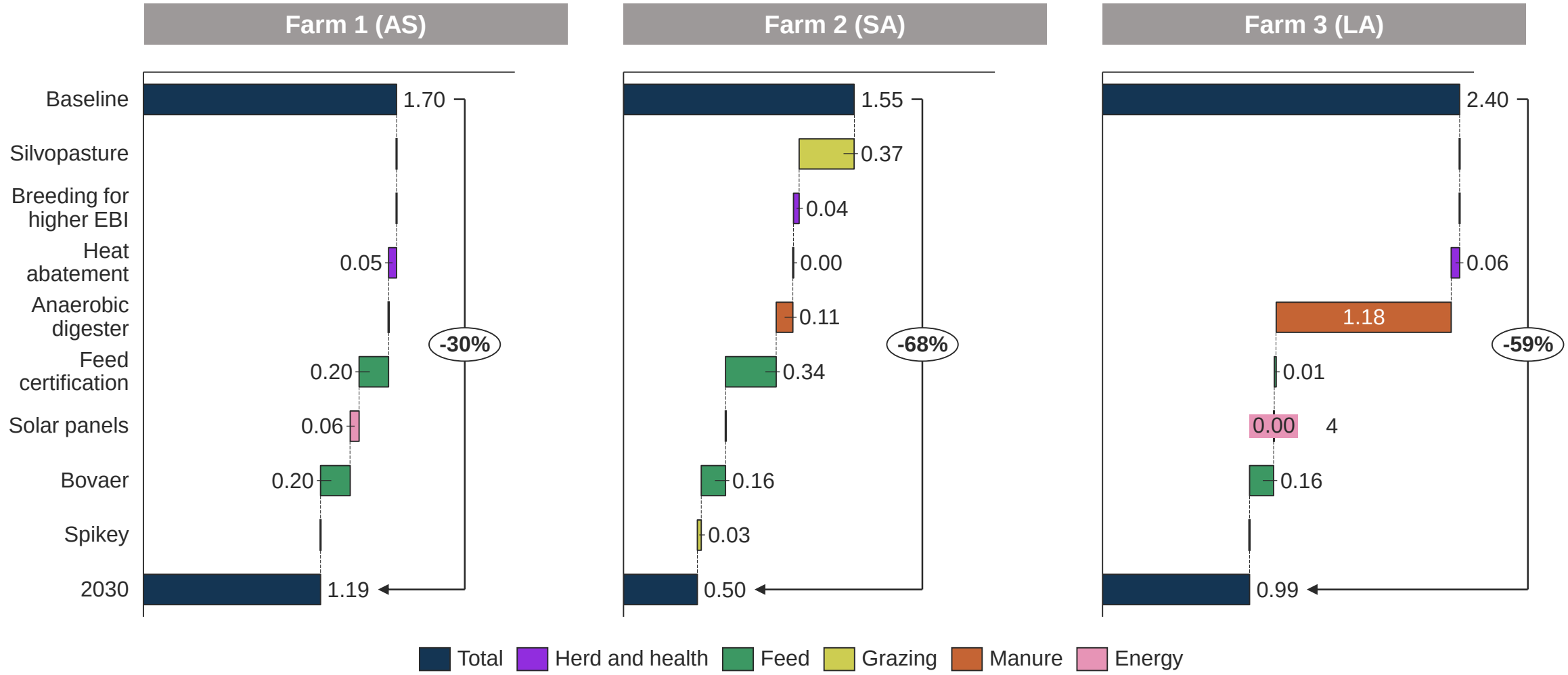
I.	Summary	2
II.	Methodology	9
1.	Case farms and abatement lever selection	10
2.	Modelling	22
III.	Results	33
IV.	Outlook	39

Outcome | Emissions could be reduced between 30 and 68%, of which significant reductions achieved at negative or low costs

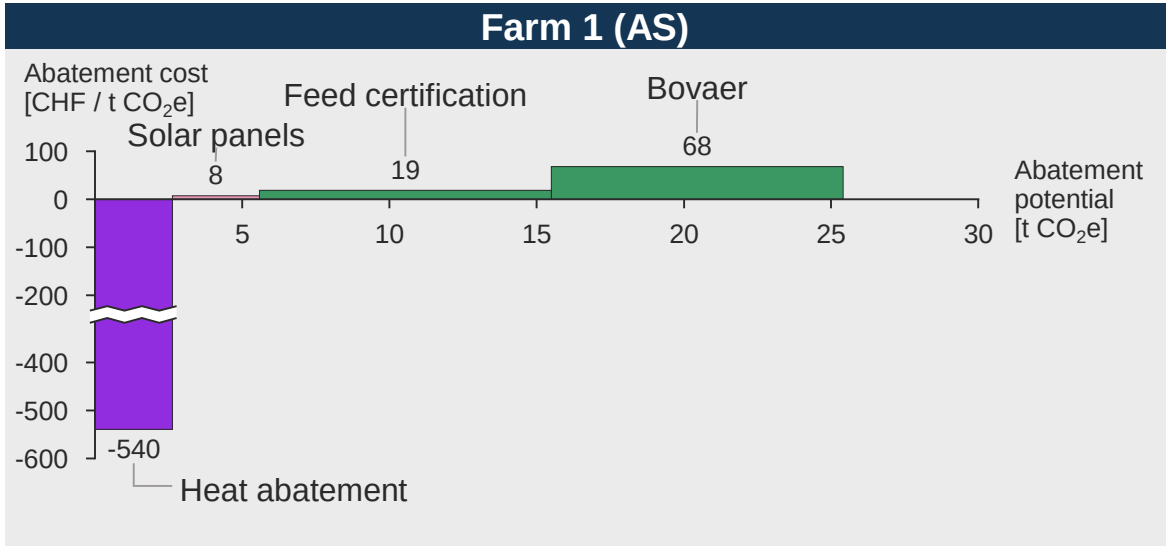
Cost and emission intensity of a liter of milk at different abatement costs

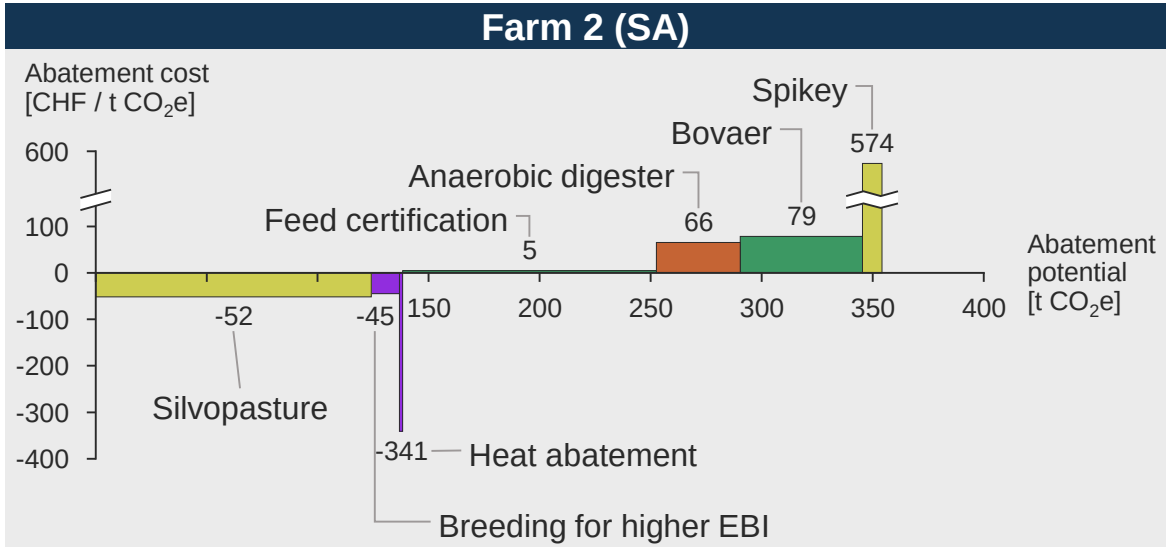
	No levers	<20 CHF/tCO2e		<100 CHF/tCO2e		All levers	
Farm 1 (AS)	1L, 0.400 CHF, CO_2 1.70	• Heat abatement • Solar panels	1L, 0.376 CHF, CO_2 -7%	• Feed certification • Bovaer	1L, 0.389 CHF, CO_2 -30%		
Farm 2 (SA)	1L, 0.400 CHF, CO_2 1.55	• Silvopasture • Breeding program • Heat abatement • Feed certification	1L, 0.379 CHF, CO_2 -48%	• Anaerobic digester • Bovaer	1L, 0.400 CHF, CO_2 -67%	• Spikey	1L, 0.415 CHF, CO_2 -68%
Farm 3 (LA)	1L, 0.400 CHF, CO_2 2.40	• Heat abatement	1L, 0.384 CHF, CO_2 -2%	• Anaerobic digester • Bovaer	1L, 0.463 CHF, CO_2 -58%	• Certified feed • Solar panels	1L, 0.466 CHF, CO_2 -59%

Results | The abatement potential that can be achieved differs between the case farms, mostly based on which levers can be implemented

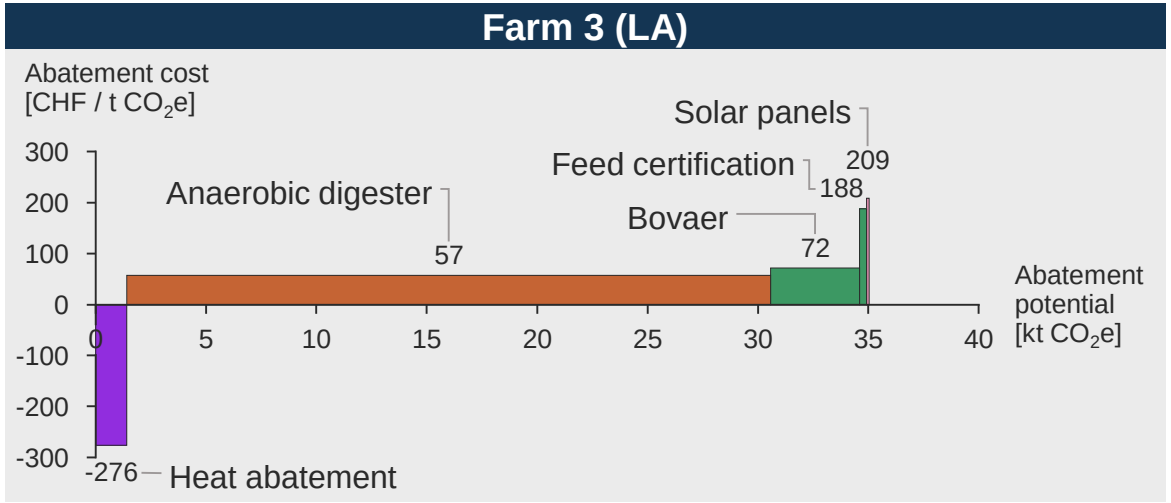


Results | Although abatement potential and cost differ, the farms have a similar order of implementation based on the MACC





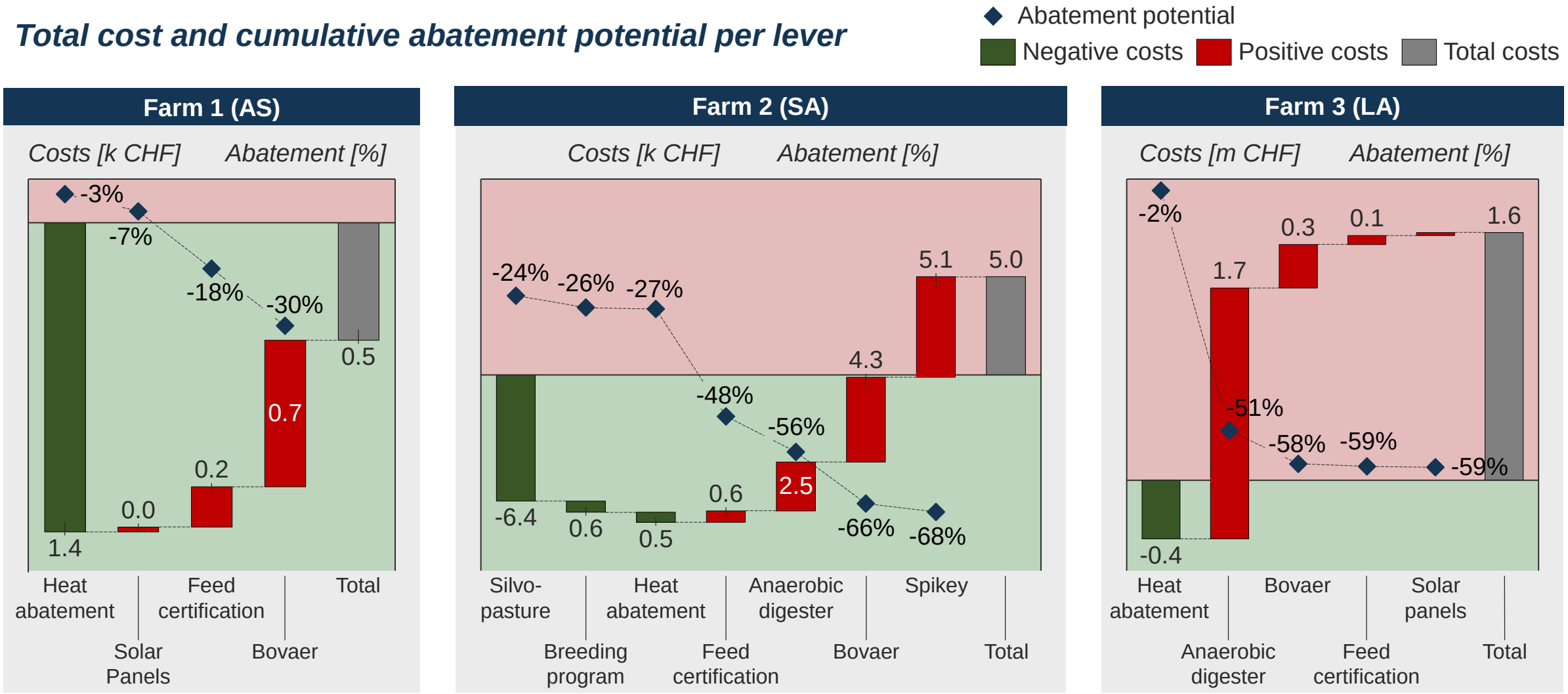
- Herd and health
- Feed
- Grazing
- Manure
- Energy



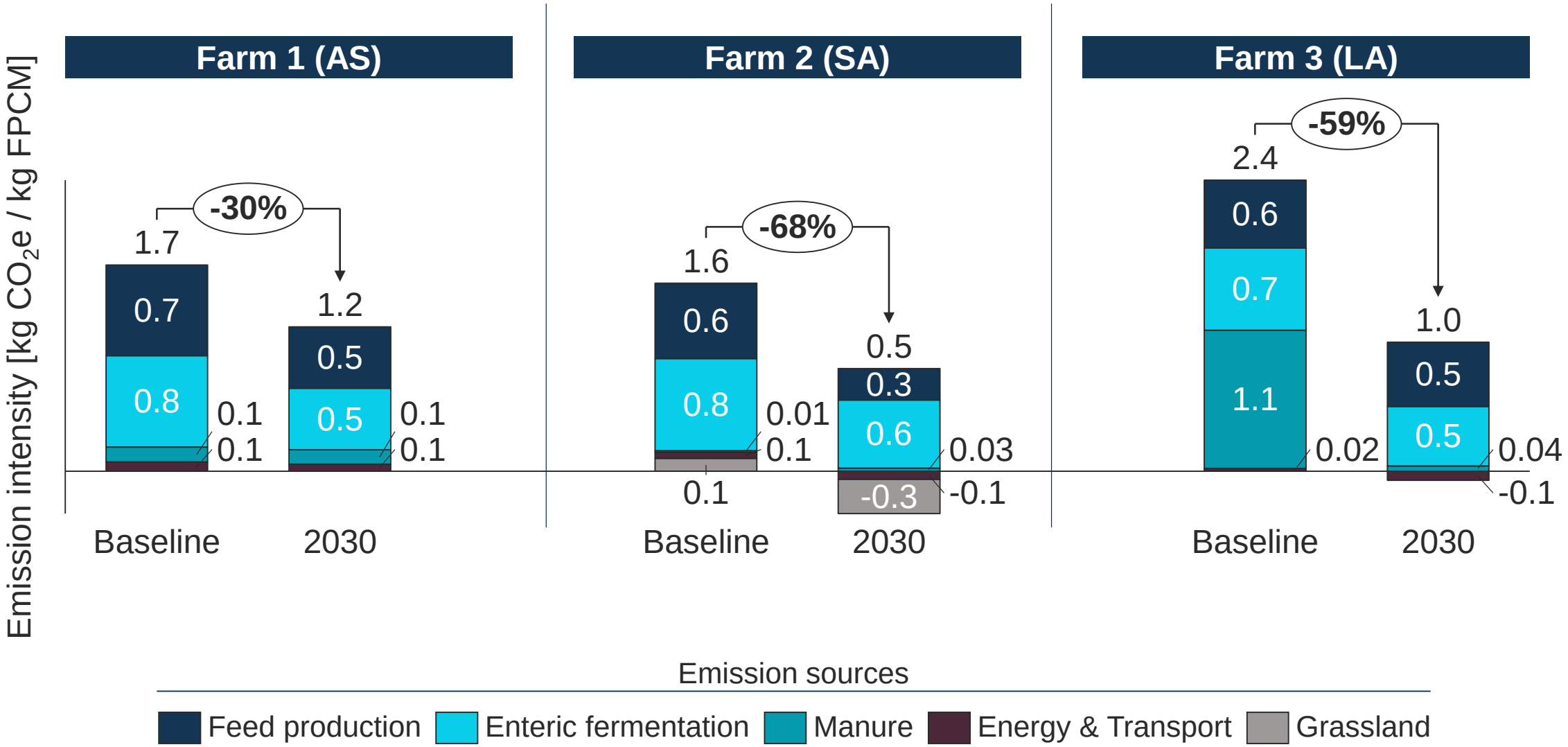
Source: MACC = Marginal abatement Cost Curve

Results | Profit from negative cost measures can be used to pay for more costly measures, resulting in a larger reduction at no cost

Total cost and cumulative abatement potential per lever



Results | If all levers are implemented, enteric fermentation and feed production remain the largest sources of emissions



Contents

I.	Summary	2
II.	Methodology	9
1.	Case farms and abatement lever selection	10
2.	Modelling	22
III.	Results	33
IV.	Outlook	39

Outlook | Each farm requires its own specific path to net zero, which is a process of continuous improvement, starting with an on-farm assessment

On-farm assessment	Improvement areas	Levers with potential and cost	Increase accuracy with data	Action plan	Implement and track
➢ On-farm assessment by or with the farmer ➢ Collect more data than needed for footprint calculations	➢ Model can be used to identify the areas with most room for improvement	➢ Mitigation potential and cost are calculated in the model for levers in improvement areas ➢ Focus on bottom line for the farmer	➢ Data can be added, e.g. on cost, to make the model more accurate for the farm	➢ Action plan based on the levers needs to be developed ➢ Concrete and implementable for the farmer	➢ As the farmer implements the action plan, the results must be tracked

Outlook | Farms can significantly reduce emissions at low or no costs, but they do require a farm specific approach

Large reductions can be achieved now, even at low or negative costs

- All farms in the model showed **significant reduction potential**, between **30 and 68%**
- **Similar reductions are likely on other farms** as well, especially as the average emission intensity in these regions is higher than that of the case farms
- The **technology to achieve these reductions is proven and available**
- If cost savings are used to finance more expensive levers, emissions reductions between 2 and 66% could be achieved while becoming more profitable
- **All on-farm emissions need to be addressed** to reach net zero**,** so there is low risk for focussing on the wrong lever

Each farm requires its own analysis to identify the optimal levers

- It significantly **differs per farm if a lever can be applied and what its potential and cost are**
- E.g. Spikey was the most expensive lever for farm 2, but is likely profitable in other regions
- A **separate analysis should thus be done for every farm system**, in collaboration with the farm
- Available land is a large indicator of the potential to reduce as it enables natural climate solutions such as silvopasture

Farms should also consider levers beyond those included in this study

- Large levers were excluded because they were not applicable to the farm or there was a lack of data, most noteworthy **health and nutrition, which both have a significant impact on emissions**
- Certain levers might not be relevant for the majority of farms, but could be key to decarbonisation in certain farms
- **New promising levers are still emerging**, such as breeding for lower emissions, so it is important to track this innovation

Outlook | For a successful implementation, it is key that financing and education are considered and data is collected throughout the process

Companies should consider different financing options to support the farmers

- Most farmers are **under high economic pressure and have low margins**, hence they cannot be expected to finance these levers
- Even when a lever results in cost savings, **farmers need support for investments**
- Dependent on the farmer and the lever, **different financing solutions** should be used, e.g. direct financing the lever or leveraging their more favourable financing options
- In the farms modelled, 10-25% of emission reductions were allocated to meat production, but the **full costs are borne by the dairy company**, thus increasing the abatement costs
- Hence, the costs of decarbonization could be reduced if the **emission reductions allocated to meat are monetized**, e.g. through offsetting

Education and support to alleviate managerial requirements are vital

- Most levers require additional education to be set-up and management
- Companies can support **setting up education programs**, e.g. with peer-to-peer learning
- Some levers require more active management, increasing the managerial bandwidth required
- Solutions should be found to **alleviate the additional workload** where this is desired by farmers, e.g. there are companies that can be hired to do manure management, thus allowing the farmer to focus on different tasks

Improve effectiveness and trust through pilots and data collection

- Even when the whole pathway to net zero is not defined yet, pilot studies can be done
- **More data collection will improve the various emission- and cost models** that are used and validate them for different countries and farms
- Data on successful implementation will **pave the way for further acceptance** and implementation within the community

This project was a collaboration between sus.lab at ETH Zurich and Nestlé

Authors:
Ms. Dianne Hondeborg, Project Manager at sus.lab, Group for Sustainability and Technology, ETH Zurich
Ms. Marija Spokaite, Project Manager at sus.lab, Group for Sustainability and Technology, ETH Zurich
Dr. Petrissa Eckle, Director of sus.lab, Group for Sustainability and Technology, ETH Zurich
Dr. Catharina Bening, Senior Researcher, Group for Sustainability and Technology, ETH Zurich
Mr. Robert Markus Erhard, Corporate Sustainable Agriculture, Livestock, Nestlé
Ms. Róisín Murphy, Origin Green Ambassador, Bord Bia

Special thanks to all experts who contributed to the project through interviews and sharing expertise

Based on the master thesis:

- “Pathways to Net Zero – A Case study on Greenhouse Gas Reduction for Dairy Farms”
- In collaboration with Nestlé
- Submitted in April 2020 at the Group for Sustainability and Technology, ETH Zurich

References

1. Berry, D., Shalloo, L., Cromie, A., Olori, V., Veerkamp, R., Dillon, P., Amer, P., Evans, R., Kearney, F., & Wickham, B. (2007). *The economic breeding index: a generation on*. Irish Cattle Breeding Federation.
2. Cambridge Institute for Sustainability Leadership (2015). Doing Business with Nature: Opportunities from natural capital. https://www.cisl.cam.ac.uk/resources/publication-pdfs/doing-business-with-nature.pdf
3. Canaza-Cayo, A. W., Cobuci, J. A., Lopes, P. S., de Almeida Torres, R., Martins, M. F., dos Santos Daltro, D., & Barbosa da Silva, M. V. G. (2016). Genetic trend estimates for milk yield production and fertility traits of the Girolando cattle in Brazil. *Livestock Science*, *190*, 113–122. https://doi.org/10.1016/J.LIVSCI.2016.06.009
4. Cool Farm Alliance. (2019). *Cool Farm Tool Technical Documentation - V1.0 corresponding CFT v0.8.17* (B. Kayatz, C. von Tonder, J. Hillier, J. P. Lesschen, & L. Dicks (Eds.)).
5. Cubbage, F., Balmelli, G., Bussoni, A., Noellemeyer, E., Pachas, A. N., Fassola, H., Colcombet, L., Rossner, B., Frey, G., Dube, F., de Silva, M. L., Stevenson, H., Hamilton, J., & Hubbard, W. (2012). Comparing silvopastoral systems and prospects in eight regions of the world. *Agroforestry Systems*, *86*(3), 303–314. https://doi.org/10.1007/s10457-012-9482-z
6. Culliney, K. (2018). *Putting a price on soy? Industry chews over how sustainability costs should be shared*. https://www.feednavigator.com/Article/2018/06/05/Putting-a-price-on-soy-Industry-chews-over-how-sustainability-costs-should-be-shared
7. De Vries, A., Overton, M., Fetrow, J., Leslie, K., Eicker, S., & Rogers, G. (2008). Exploring the Impact of Sexed Semen on the Structure of the Dairy Industry. *Journal of Dairy Science*, *91*(2), 847–856. https://doi.org/10.3168/JDS.2007-0536
8. Eory, V., Macleod, M., Faverdin, P., de Oliveira Silva, R., Barioni, L. G., Albertini, T. Z., Topp, K., Fernandes, F. A., & Moran, D. (2015). *Report on developing bottom-up Marginal abatement cost curves (MACCS) for representative farm type*.

References

9. FAO. (2010). *Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment*.
10. FAO & Global Dairy Platform. (2018). *Climate change and the global dairy cattle sector – The role of the dairy sector in a low-carbon future*.
11. GRA, & SAI. (2015). *Reducing greenhouse gas emissions from livestock: Best practice and emerging options* (K. Andeweg & A. Reisinger (Eds.)). SAI Platform.
12. Hristov, A. N., Oh, J., Firkins, J. L., Dijkstra, J., Kebreab, E., Waghorn, G., Makkar, H. P. S., Adesogan, A. T., Yang, W., Lee, C., Gerber, P. J., Henderson, B., & Tricarico, J. M. (2013a). Special Topics - Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *Journal of Animal Science*, *91*(11), 5045–5069. https://doi.org/10.2527/jas.2013-6583
13. Hristov, A. N., Ott, T., Tricarico, J. M., Rotz, A., Waghorn, G., Adesogan, A. T., Dijkstra, J., Montes, F., Oh, J., Kebreab, E., Oosting, S. J., Gerber, P. J., Henderson, B., Makkar, H. P. S., & Firkins, J. L. (2013b). Special Topics - Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. *Journal of Animal Science*, *91*(11), 5095–5113. https://doi.org/10.2527/jas.2013-6585 .
14. International Dairy Federation. (2016). *Bulletin of the International Dairy Federation 485/2016 The World Dairy Situation 2016*. Retrieved December 13, 2019, from www.fil-idf.org
15. IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (Eds). Published: IGES, Japan.
16. IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (Eds). Published: IPCC, Switzerland.

References

17. Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A. N., Oh, J., Waghorn, G., Gerber, P. J., Henderson, B., Makkar, H. P. S., & Dijkstra, J. (2013). Special Topics - Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *Journal of Animal Science*, *91*(11), 5070–5094. https://doi.org/10.2527/jas.2013-6584
18. Montoro, S. B., Santos, D. F. L., & de Lucas Junior, J. (2017). Economic and financial viability of digester use in cattle confinement for beef. *Engenharia Agricola*, *37*(2), 353–365. https://doi.org/10.1590/1809-4430-Eng.Agric.v37n2p353-365/2017
19. New Zealand Ministry for Primary Industries. (2013). *DCD suspension supported*. https://www.mpi.govt.nz/news-and-resources/media-releases/dcd-suspension-supported/
20. OECD, & FAO. (2019). *OECD-FAO Agricultural Outlook 2019-2028*. OECD Publishing. https://doi.org/10.1787/agr_outlook-2019-en
21. Scientific Committee on Animal Health and Animal Welfare. (1999). *Animal Welfare Aspects of the Use of Bovine Somatotrophin*.
22. St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2003). Economic Losses from Heat Stress by US Livestock Industries. *Journal of Dairy Science*, *86*, E52–E77. https://doi.org/10.3168/JDS.S0022-0302(03)74040-5
23. Van Knegsel, A. T. M., Remmelink, G. J., Jorjong, S., Fievez, V., & Kemp, B. (2014). Effect of dry period length and dietary energy source on energy balance, milk yield, and milk composition of dairy cows. *Journal of Dairy Science*, *97*(3), 1499–1512. https://doi.org/10.3168/JDS.2013-7391

sus.lab @ Group for Sustainability & Technology, ETH Zurich | Weinbergstrasse 56/58 | WEV J 423 | CH-8092 Zurich

Contact Petrissa Eckle, PhD | contact_suslab@ethz.ch | www.suslab.ch

www.suslab.ch