PRODUCT ENVIRONMENTAL FOOTPRINT

Organic Clover Grass Protein Concentrate

Benyamin Khoshnevisan
Assistant Professor
University of Southern Denmark (SDU)
Section of Life Cycle Engineering (LCE)
+ 45 91 40 21 91
bekh@igt.sdu.dk

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AGENDA

- PEF and PEFCR
- Grass Protein Concentrate producers
- Compound Feed Producers
- PEF and policy decision making

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Græs-Prof project:
WP 5 – Environmental Footprint

- PEF of organic clover grass protein concentrate

- PEF of compound feed with organic clover grass protein concentrate

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European Commission

JOINT RESEARCH CENTRE

Product Environmental Footprint & Product Environmental Footprint Category Rules

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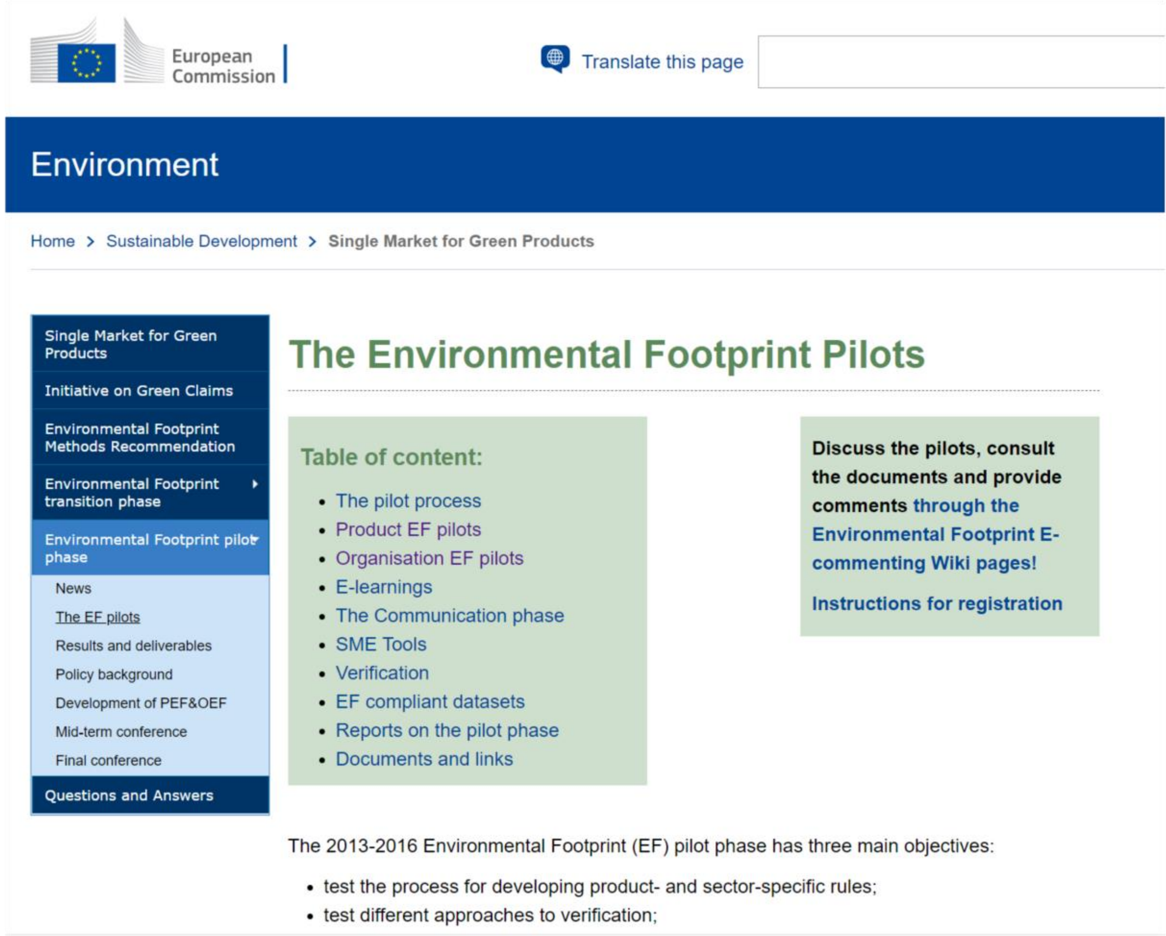
Product Environmental Footprint

- Developed by European Commission's Joint Research Center (JRC)
- Measures the environmental performance of any service or good throughout its Life Cycle.
- Ensure that environmental impacts are transparently assessed and, in the end, of course; reduced.
- Strengthen the European market for green alternatives.



https://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

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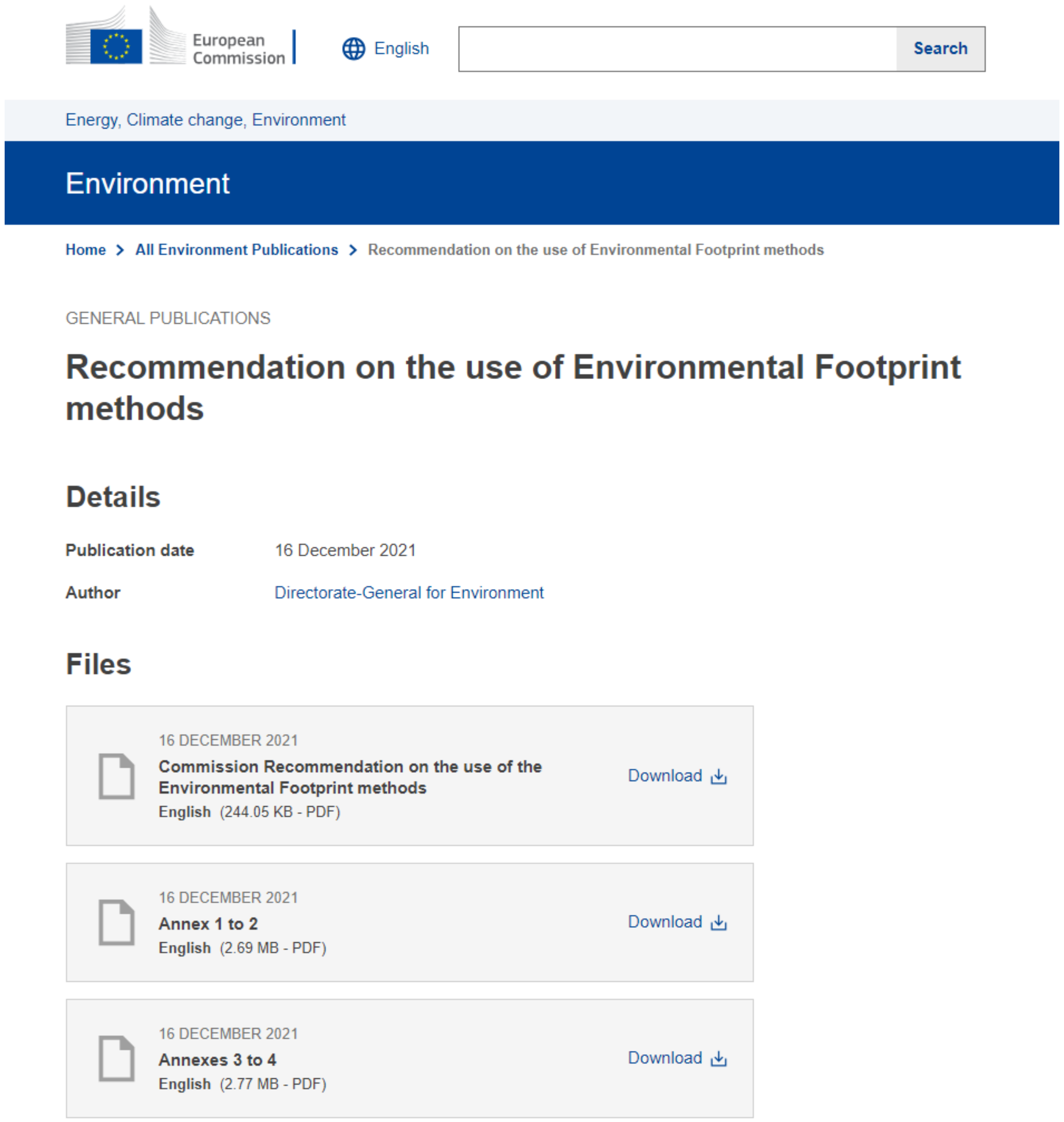
Revised recommendation on the use of EF methods

In **December 2021**, the Commission adopted a **revised Recommendation** on the use of Environmental Footprint methods, helping companies to calculate their environmental performance based on reliable, verifiable and comparable information.


European Commission | English | Search

Energy, Climate change, Environment

Environment

Home > All Environment Publications > Recommendation on the use of Environmental Footprint methods

GENERAL PUBLICATIONS

Recommendation on the use of Environmental Footprint methods

Details

Publication date	16 December 2021
Author	Directorate-General for Environment

Files

16 DECEMBER 2021
Commission Recommendation on the use of the Environmental Footprint methods
English (244.05 KB - PDF) Download

16 DECEMBER 2021
Annex 1 to 2
English (2.69 MB - PDF) Download

16 DECEMBER 2021
Annexes 3 to 4
English (2.77 MB - PDF) Download

https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en

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Product Environmental Footprint Category Rules

PEFCR	Valid until	Additional files
Beer Corrigendum	31/12/2021	Life cycle inventory Excel model of the RP Beer
Dairy Corrigendum	31/12/2021	Life cycle inventory Critical review report Other guidance documents Excel models of the RP Dairy
Decorative paints Corrigendum	31/12/2021	Life cycle inventory
Household liquid laundry detergents	31/12/2021	Excel model of the RP detergents
Hot and cold water supply pipe systems Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP water supply
Intermediate paper product Corrigendum	31/12/2021	Life Cycle Inventory (mandatory company-specific data) Excel model of the RP intermediate paper
Feed for food producing animals Corrigendum	31/12/2021	Life Cycle Inventory
IT equipment Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP IT equipment

Leather Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP Leather
Metal sheets	31/12/2021	Life Cycle Inventory Critical review report Excel model of the RP Metal sheets
Packed water Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP Packed water
Pasta Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP Pasta
Pet Food Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP Pet food
Photovoltaic electricity production	31/12/2021	Life Cycle Inventory Excel model of the RP Photovoltaic Corrigendum
Rechargeable batteries Corrigendum	31/12/2021	Life Cycle Inventory Excel model of the RP Rechargeable batteries
T-shirt	31/12/2020	Life Cycle Inventory Excel model of the RP Tshirt

- 25 product categories
- 2 organization sectors

https://wayback.archive-it.org/org-1495/20221004164603mp_/https:/ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm

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Applications of PEF studies with/without an existing PEFCR

In-house application

- optimisation of processes along the life cycle of a product
- support to environmental management
- identification of environmental hotspots
- support for product design minimising environmental impacts
- environmental performance improvement and tracking

External Application

- responding to customers and consumers demands
- participation in 3rd party schemes related to environmental claims
- green Procurement
- comparisons and comparative assertions
- comparison and comparative assertions against the benchmark of the product

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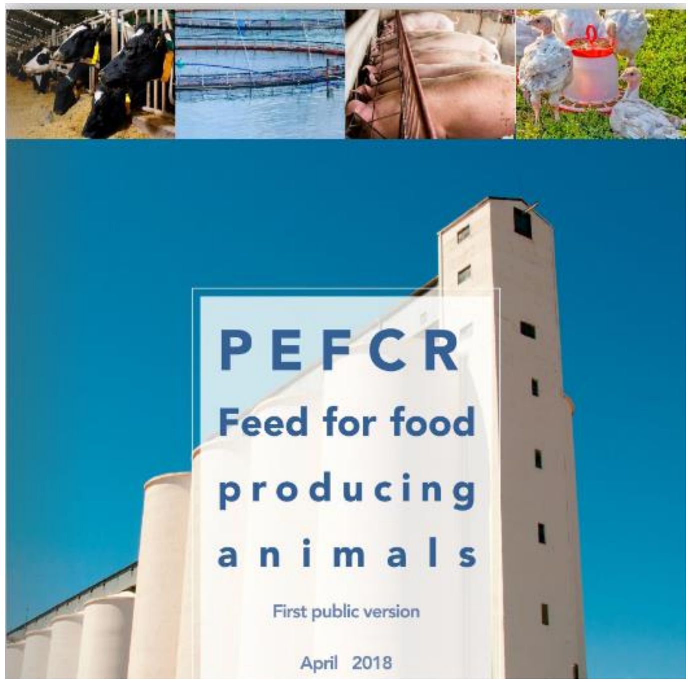
PEF organic clover grass protein concentrate



PEFCR Feed for food-producing animals

Version 4.2

February 2020 (original publication date: April 2018)

https://wayback.archive-it.org/org-1495/20221006221936mp_/https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Feed_Feb%202020.pdf

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PEFCR Feed for Food Producing Animals

PEFCR scope is CPA 10.91 “Manufacture of prepared feeds for farm animals (Eurostat ISSN 1977-0375)”

- manufacture of *prepared feeds* for farm animals
- preparation of *unmixed (single) feeds* for farm animals
- treatment of slaughter by-products to produce animal feeds and explicitly excludes:
  - production of fishmeal for animal feed, CPS 10.20
  - production of oilseed cake, CPA 10.41
  - activities resulting in by-products usable as animal feed without special treatment

CPA: Classification of Products by Activity

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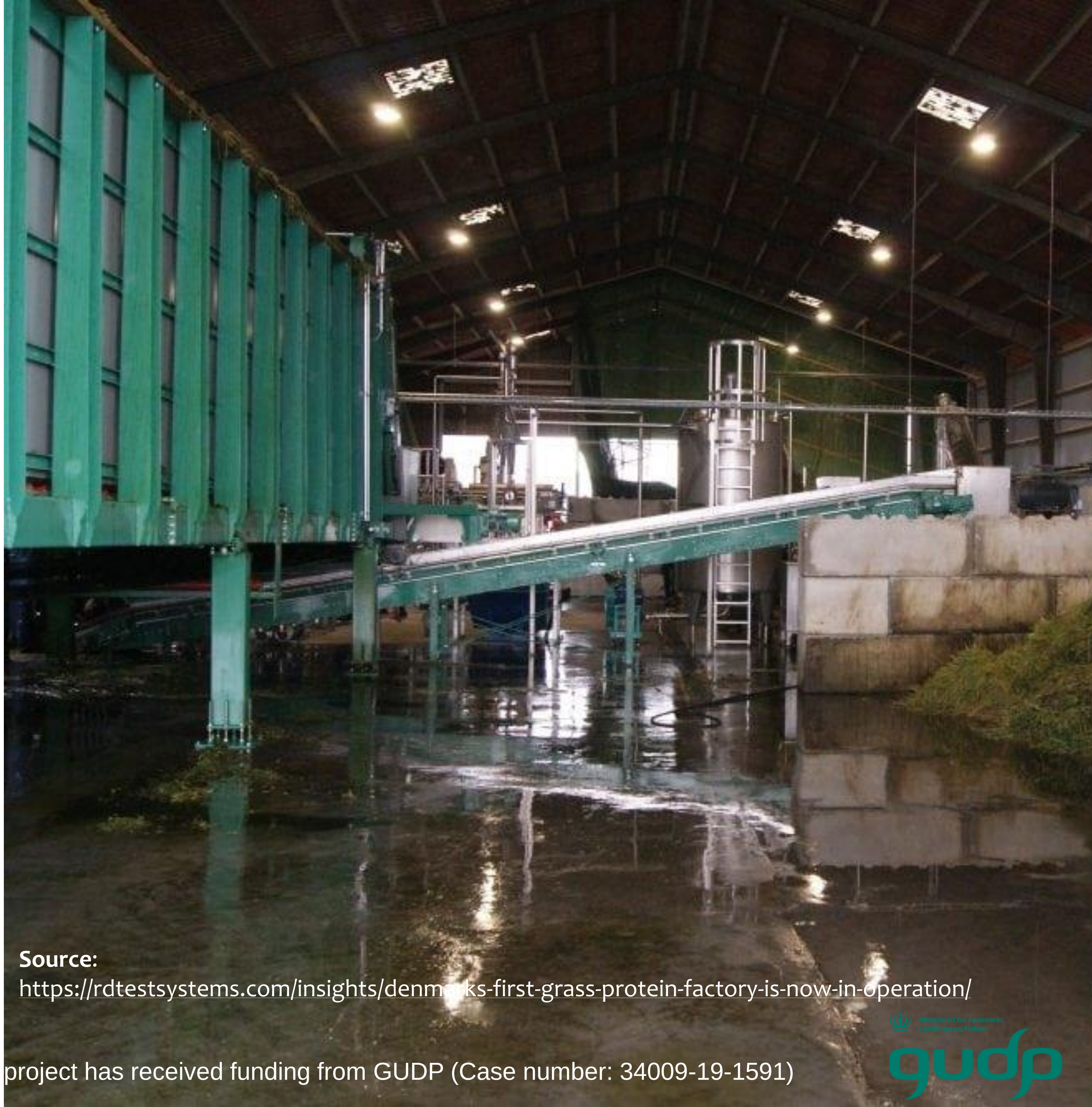
Goal of study

- Protein Concentrate produced from organic clover grass
- Product of Assumgaard Biorefinery
- GPC with 90% dry matter
- Crude protein content of 47%
- Dried and ready to deliver to compound feed producers

Note: Early assessment as process still needs to optimized



Source:
https://rdtestsystems.com/insights/denmarks-first-grass-protein-factory-is-now-in-operation/

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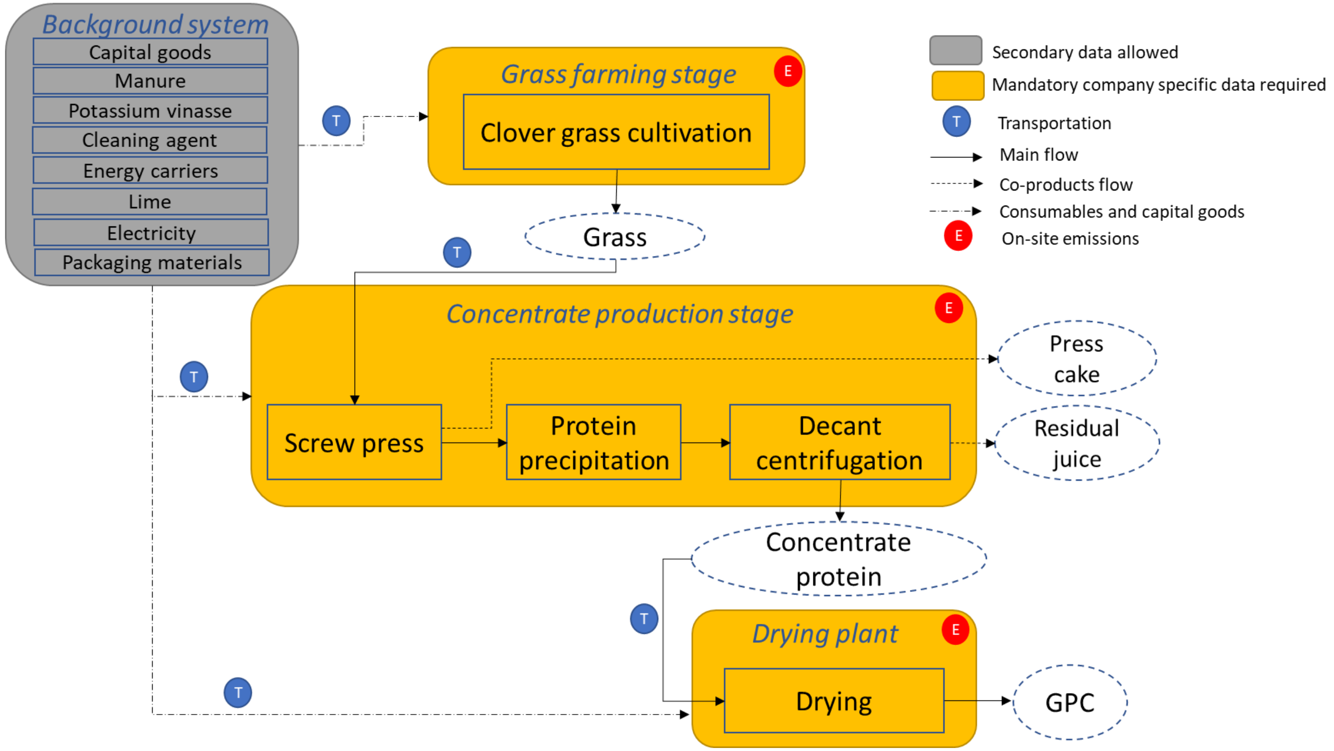
System boundary & life cycle stages

Life cycle stage	Short description of the processes included
Organic grass cultivation	Organic grass used for GPC is cultivated in Ausumgaard farm and surrounding farms. The cultivation of organic grass requires the input of manure and biogas slurry as well as energy carriers, water, auxiliary materials and may involve land transformation. The full life cycle of the production of these products, including transport and depreciation of capital goods is in the scope of this PEF study.
Inbound transportation	The delivery of harvested grass to the biorefinery plant is part of the life cycle of GPC.
Production of GPC	GPC production is the core of this PEF study where the delivered grass is processed to the final product and leaves two important co-products namely press cake and brown juice.
Outbound transportation	The transportation of intermediate protein concentrate to the drying facility as well as transportation of co-products are included in the scope of this study.
Processing of coproducts	The processing of the coproducts does not belong to the scope of this PEF study.



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Assessment requirements, modeling approach/assumptions

- **Direct land use change** shall be taken into account in the PEF studies. GHG emissions and removals arising from land use change (e.g. from grass land to annual crop) *occurring not more than 20 years*.
  - Assumption: Lands are under cultivation for more than 20 years.

- **Soil Carbon Stock** shall *be excluded* from the results, e.g. from grasslands or improved land management through tilling techniques or other management measures taken related to agricultural land.

- The agricultural inputs (e.g., manure, seeds, irrigation water) for cultivation stage shall be modeled under *steady state of production*. A period of at least 3 years shall be used.
  - Modeling approach: Average of 3 years was considered as steady state production.
  - Modeling approach: No watering at Ausumgaard. *Irrigation is excluded* from the basis calculation. It was considered as part of a sensitivity calculation.

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Assessment requirements, modeling approach/assumptions

- **Farm rotation** shall be included.
  - Modeling approach: Grass-clover seed is undersown in cereals and the next *two years* the grass-clover is cut *six times* during the season.

- CO_2 emissions related to application of all products containing fossil carbon (CO_2 emissions from lime and peat are considered 100% fossil).
  - Modeling approach: 1.5 t/ha every fifth year equal to 233 kg lime/ha.yr as realistic.

- Default emission factors for N and P-based emissions can be used when a more comprehensive field emission model is not available.
  - Modeling approach: Emission factors differentiated synthetic and organic fertilizers.
  - NH_3 (organic fertilizers) = 0.24 kg NH_3 / kg N organic fertilizers applied to air
  - (NH_3 for synthetic fertilizers = 0.12 kg NH_3 / kg N fertilizers applied).
  - N_2O (organic and synthetic fertilizers) = 0.022 kg N_2O/kg N applied to air
  - NO_3^- (organic and synthetic fertilizers) = 1.33 kg NO_3^- / kg N applied to water

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Assessment requirements, modeling approach/assumptions

- Allocation shall be applied between main product (GPC) and by-products (i.e., fiber and brown juice):
  - Modeling approach: Economic allocation was applied.
  - Allocation factors: 74% to GPC, 7% to Brown juice, 19% to Press cake.

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Life Cycle Inventory Data – Reference flow 1 tonne GPC

Inputs	Unit	Quantity	Comment
Fresh grass	kg	32,665.51	
Electricity, processing	kWh	108.77	
Electricity, drying	kWh	280.07	
Acidic cleaning agent	kg	2.20	
Alkaline cleaning agent	kg	10.80	
Water	m^3	0.48	
Antifoam	kg	1.30	
Natural gas	m^3	85.02	LHV = 36.6 MJ/m^3, 47.1 MJ/kg, 0.777 kg/m^3
Packaging materials	kg	3	
Diesel, loading	l	8.1	
Diesel, heating	l	56.92	
Buildings, biorefinery	kg	17.01	
Buffer feed tank	kg	0.33	
Screw press	kg	1.12	
Heat exchanger	kg	0.22	
Centrifuge	kg	0.14	
Pipes	kg	0.19	
Transport container	kg	0.11	
Telescopic loader	kg	0.216	
Buffer juice tank	kg	0.11	
Transport, packaging materials	tkm	3.30	
Transport, grass	tkm	257.24	
Transport, acidic cleaning agent	tkm	0.21	
Transport, antifoam	tkm	0.14	
Transport, alkaline cleaning agent	tkm	1.02	
Transport, intermediate product	tkm	85.59	

Outputs	Unit	Quantity	Comment
Protein concentrate	kg	1000	
Brown juice	kg	18,740	
Press cake	kg	12,125	
CO_2, diesel combustion	kg	172.43	Air
SO_2, diesel combustion	g	55.82	Air
CH_4, diesel combustion	g	7.13	Air
Benzene (C_6H_4), diesel combustion	g	0.40	Air
Cadmium (Cd), diesel combustion	g	0.001	Air
Chromium (Cr), diesel combustion	g	0.003	Air
Copper (Cu), diesel combustion	g	0.094	Air
N_2O, diesel combustion	g	6.32	Air
Nickel (Ni), diesel combustion	g	0.004	Air
Zink (Zn), diesel combustion	g	0.055	Air
Benzo(*a*)pyrene ($C_{20}H_{12}$), diesel combustion	g	0.002	Air
Ammonia (NH_3), diesel combustion	g	1.105	Air
Selenium (Se), diesel combustion	g	0.001	Air
HC, as NMVOC, diesel combustion	g	106.11	Air
NOx, diesel combustion	g	1844.19	Air
CO, diesel combustion	g	418.91	Air
PM, diesel combustion	g	51.95	Air
CO_2 from lubricant, diesel combustion	g	140.37	Air
SO_2, natural gas combustion	g	1.34	Air
NOX, natural gas combustion	g	102.81	Air
NMVOC, natural gas combustion	g	6.22	Air
CH_4, natural gas combustion	g	3.11	Air
CO, natural gas combustion	g	87.12	Air
CO_2, natural gas combustion	kg	177.55	Air
N_2O, natural gas combustion	g	3.11	Air
NH_3, natural gas combustion	g	0.00	Air
TSP, natural gas combustion	g	0.31	Air
PM_{10}, natural gas combustion	g	0.31	Air
$PM_{2.5}$, natural gas combustion	g	0.31	Air

https://doi.org/10.1016/j.scitotenv.2023.162858

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Impact categories, normalization, and weighting

Impact category	Indicator	Unit
Acidification	Accumulated Exceedance (AE)	mol H+ eq
Climate change (Total)	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2 eq
Climate change-Biogenic (methane)		kg CO_2 eq
Climate change-fossil		kg CO_2 eq
Climate change-Land use and land use change		kg CO_2 eq
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe
Eutrophication marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh
Human toxicity, non-cancer		CTUh
Ionizing radiation, human health	Human exposure efficiency relative to U235	kBq U^{235} eq
Land use	· Soil quality index · Biotic production · Erosion resistance · Mechanical filtration · Groundwater replenishment	· Dimensionless (pt) · kg biotic production · kg soil · m3 water · m3 groundwater
Particulate Matter	Impact on human health	disease incidence
Photochemical ozone formation - human health	Tropospheric ozone concentration increase	kg NMVOC eq
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq
Water use	User deprivation potential (deprivation-weighted water consumption)	m^3 world eq

Impact category	Normalization factor	Weighting factor
Acidification	55.5	0.0664
Climate change (Total)	7760.0	0.2219
Climate change-Biogenic (methane)		
Climate change-fossil		
Climate change-Land use and land use change		
Ozone depletion	0.0234	0.0675
Ecotoxicity, freshwater	11800.0	
Eutrophication marine	28.3	0.0312
Eutrophication, freshwater	2.55	0.0295
Eutrophication, terrestrial	177.0	0.0391
Human toxicity, cancer	3.85E-5	
Human toxicity, non-cancer	4.75E-4	
Ionizing radiation, human health	4220.0	0.0537
Land use	1330000.0	0.0842
Particulate Matter	6.37E-4	0.0954
Photochemical ozone formation - human health	40.6	0.051
Resource use, fossils	65300.0	0.0892
Resource use, minerals and metals	0.0579	0.0808
Water use	11500.0	0.0903

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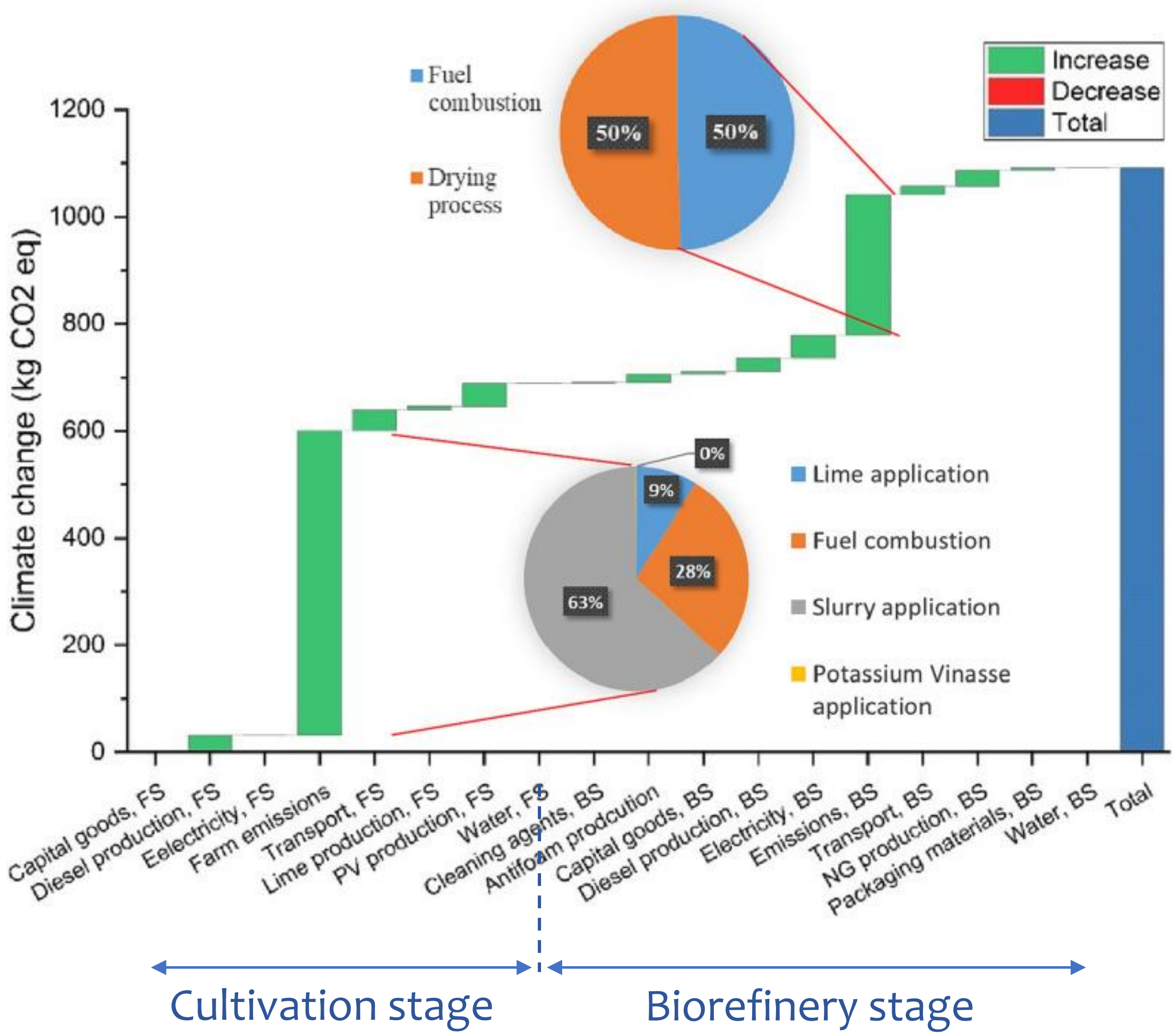
GHG emissions

- ~1090 kg CO_2,eq / tonne GPC
- Cultivation stage 63%
- Biorefinery and drying 37%
- For the farm stage:
  - Emissions from application of slurry
  - Emissions from Fuel combustion
  - CO_2 emission after lime application

- For the Biorefinery and drying stage:
  - Emissions related to in-bound transportation
  - Emissions from drying process (natural gas combustion)

- In case of irrigation (75 m^3 /ha.yr) ~1117 kg CO_2,eq / tonne of GPC



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PEF GPC *vs.* soy and soy meal

Impact category	Reference unit	GPC, Ec	Soy, GLO	Soy, EU+28	Soymeal, GLO	Soymeal, EU+28
Acidification	mol H+ eq	32.01	11.36	19.46	7.11	9.11
Climate change	kg CO2 eq	1091.47	4505.64	1545.75	2795.70	3064.29
Climate change-Biogenic	kg CO2 eq	3.20	47.43	53.90	31.54	44.10
Climate change-Fossil	kg CO2 eq	1084.56	1283.24	1452.73	879.84	1068.96
Climate change-Land use and land use change	kg CO2 eq	3.71	3174.97	39.12	1884.31	1951.23
Ecotoxicity, freshwater	CTUe	413.42	28845.52	29065.05	17832.12	17256.89
Eutrophication marine	kg N eq	16.84	10.90	17.23	6.64	7.20
Eutrophication, freshwater	kg P eq	0.47	0.49	0.39	0.30	0.39
Eutrophication, terrestrial	mol N eq	56.84	42.90	79.29	26.54	32.74
Human toxicity, cancer	CTUh	4.04E-06	8.03E-05	8.87E-05	4.92E-05	5.73E-05
Human toxicity, non-cancer	CTUh	9.71E-05	2.93E-03	3.97E-03	1.77E-03	2.11E-03
Ionising radiation, human health	kBq U-235 eq	14.48	108.86	144.31	73.98	97.25
Land use	Pt	9652.47	593597.21	531849.66	357000.04	334722.89
Ozone depletion	kg CFC11 eq	1.11E-03	1.64E-05	1.82E-05	1.09E-05	1.49E-05
Particulate Matter	disease inc.	3.41E-05	1.13E-04	1.58E-04	7.02E-05	8.21E-05
Photochemical ozone formation - human health	kg NMVOC eq	0.93	3.97	4.13	2.93	4.38
Resource use, fossils	MJ	9357.65	14038.67	15291.77	9800.43	12526.51
Resource use, minerals and metals	kg Sb eq	3.68E-04	6.66E-03	7.48E-03	4.41E-03	6.10E-03
Water use	m3 depriv.	39.38	2854.01	6373.68	1725.97	1248.49
Weighted results (single score)	per person	0.130	0.281	0.254	0.176	0.194

- The units are per 1 ton of GPC, 917.73 kg soybean meal, and 1204.3 kg soybean, based on their average crude protein content.
- Soybean meal: DM of 88%, CP of 52% of DM (ranging from 47 to 55%)
- Soybean: DM of 89%, and CP of 40% of DM

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PEF Compound Feed with GPC

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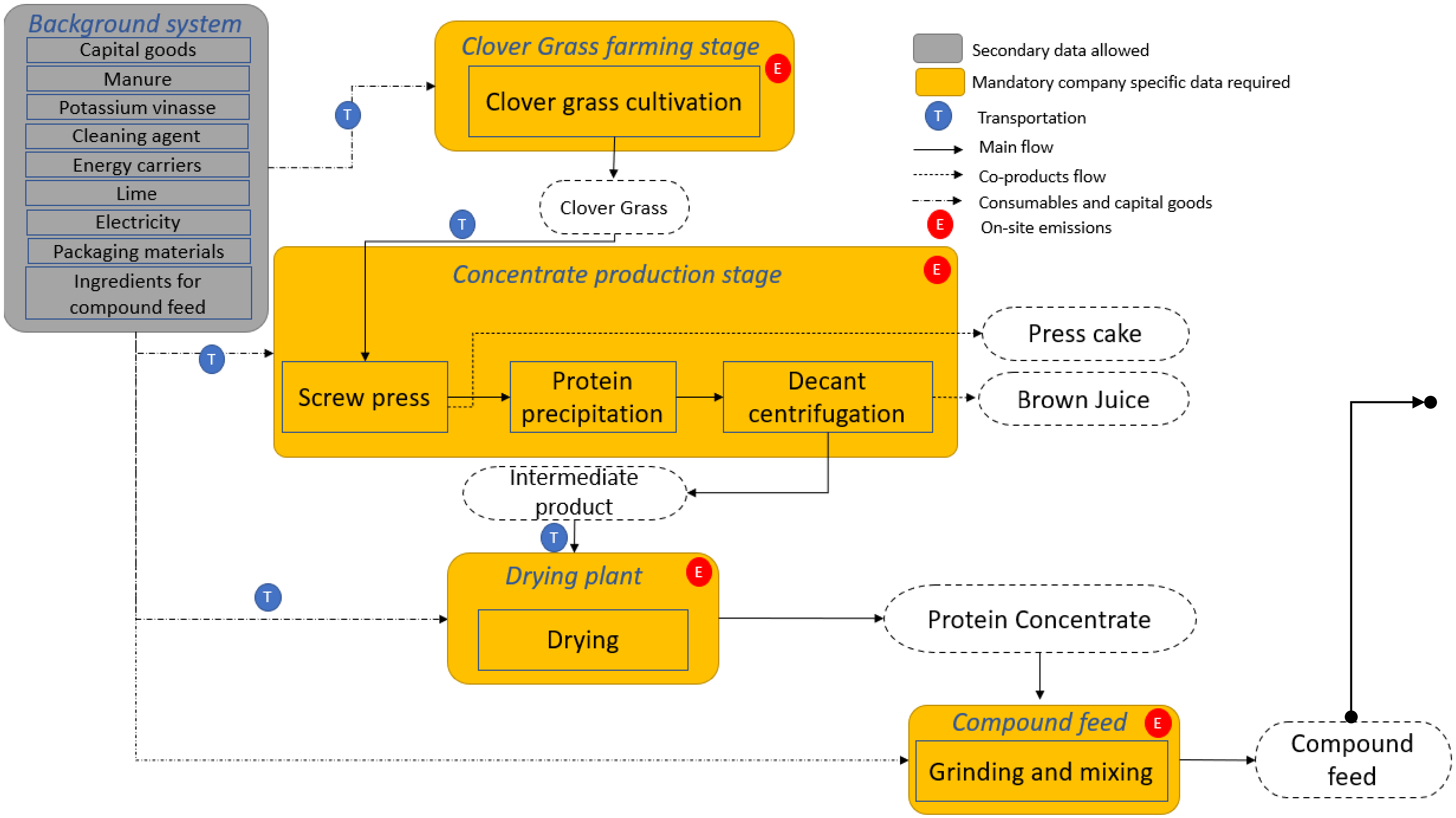
System boundary & life cycle stages



Primary data **shall** be collected for *<u>outbound transport</u>* (i.e. feed delivery to the livestock or fish farm).

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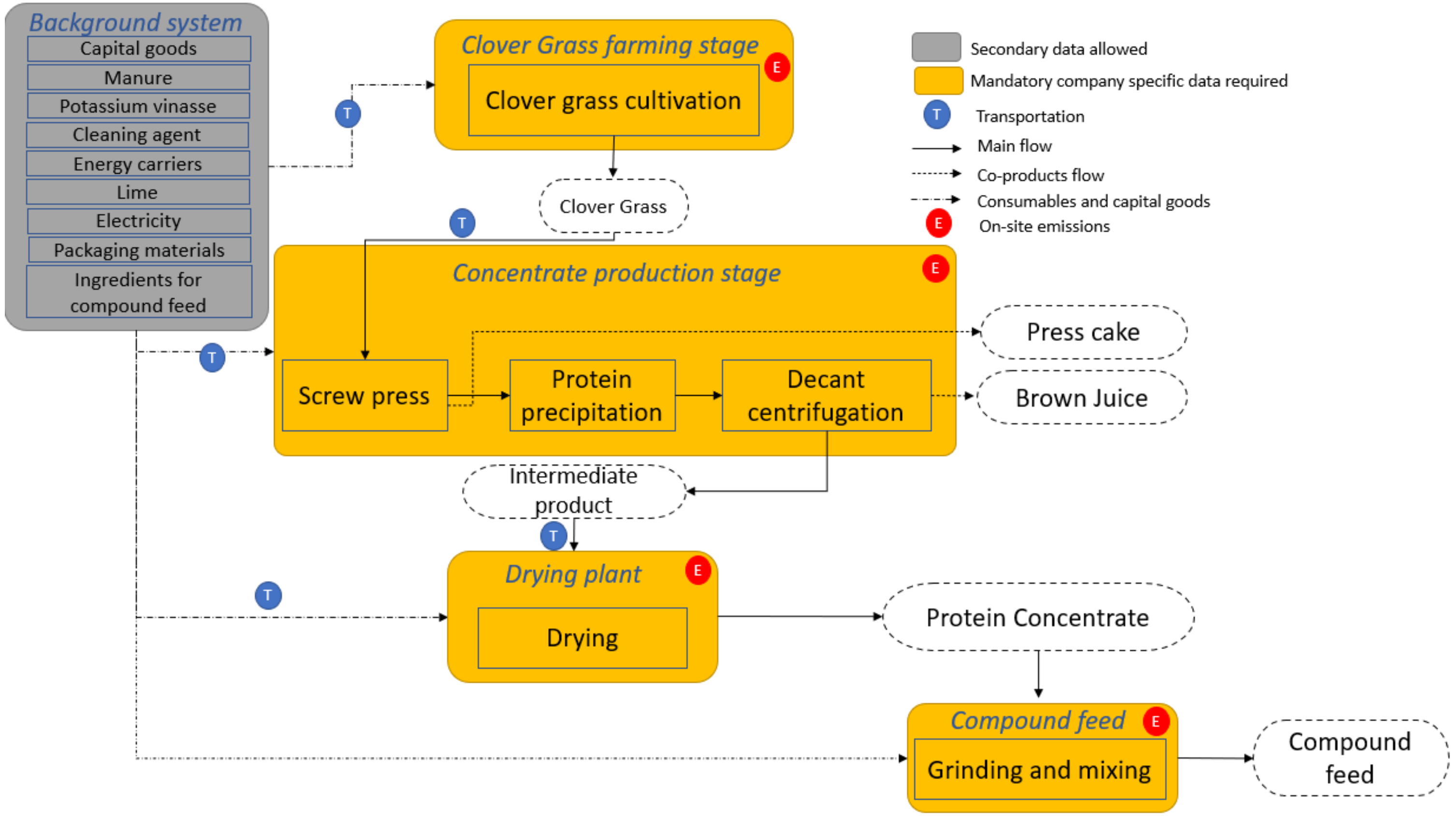
Data Source – Primary data *vs.* Secondary data

Situation 1:

- Processe run by the company (i.e., compound feed producer) applying PEFCR
  - **Option 1:** For all process provide company-specific data
  - **Option 2:** Only for most relevant process provide company-specific data and for other process use default secondary dataset.



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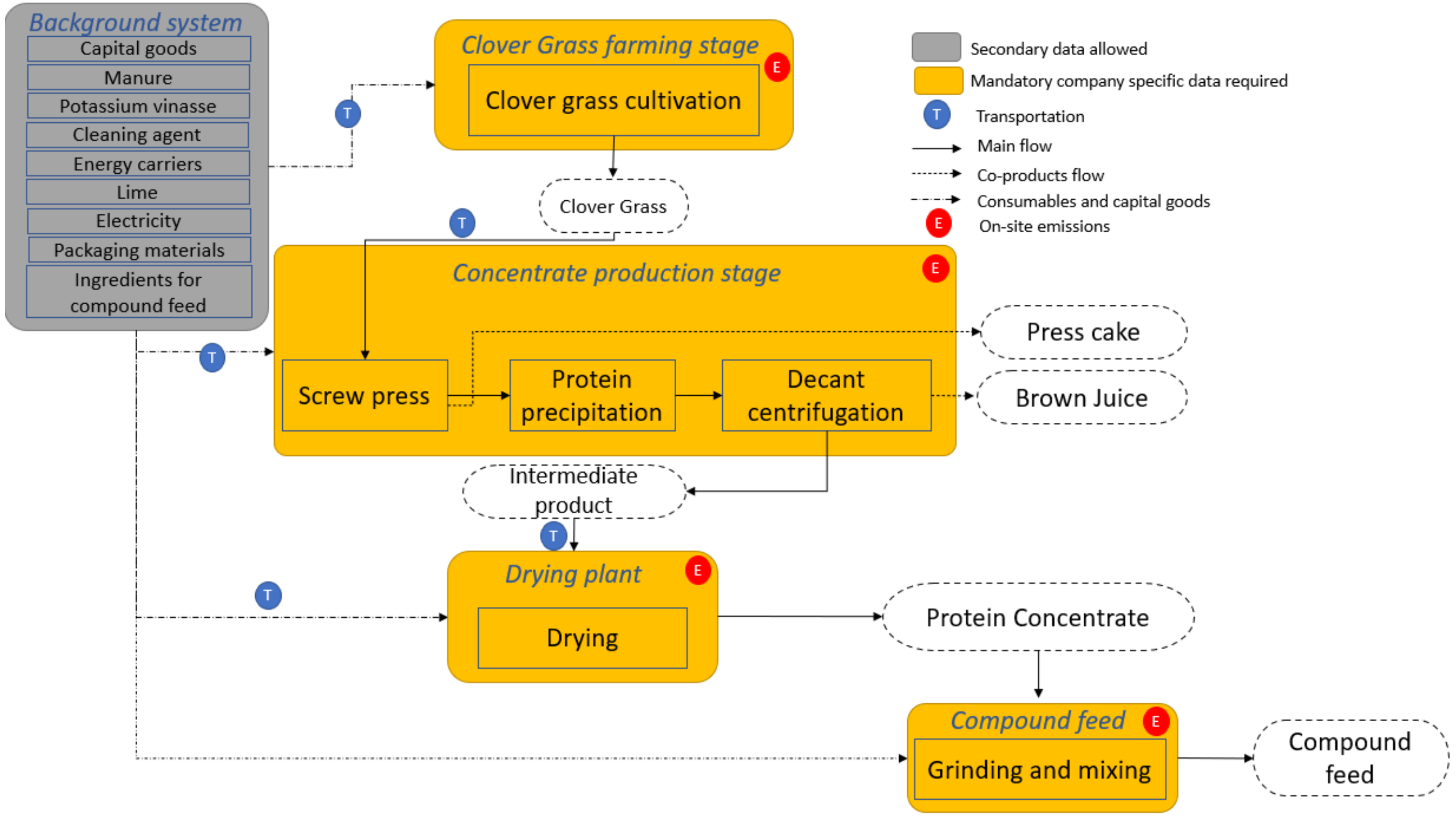
Data Source – Primary data *vs.* Secondary data

Situation 2:

- Process *not* run by the company applying the PEFCR but *with* access to (company-)specific information
  - **Option 1:** Company-specific data for all processes.
  - **Option 2:** Use company-specific data for transport (distance), and substitute electricity mix and transport with supply-chain specific PEF compliant datasets. For the rest use default dataset.



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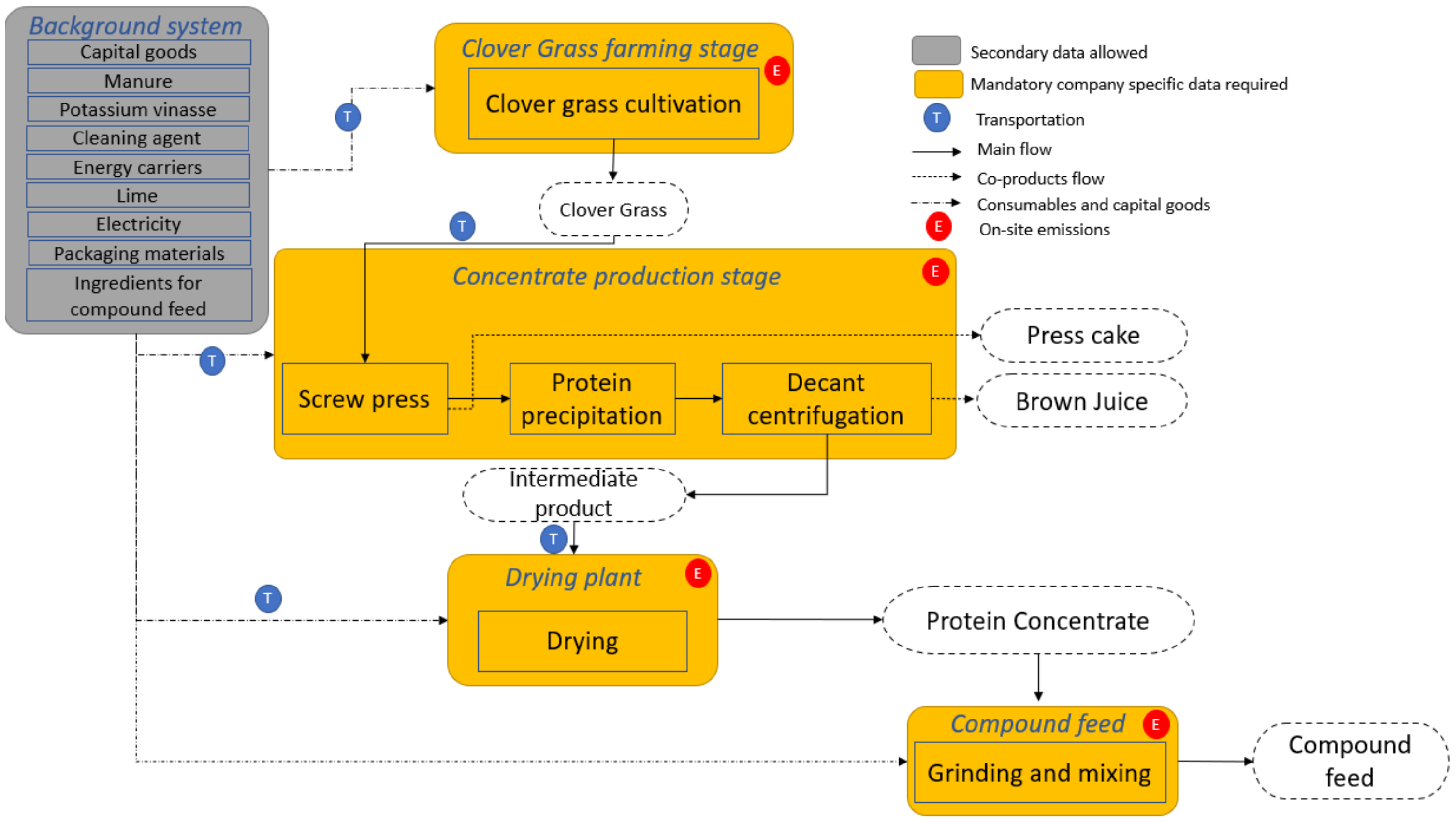
Data Source – Primary data vs. Secondary data

Situation 3:

- Process *not* run by the company applying the PEFCR but *without* access to (company-)specific information
  - Use default secondary dataset in aggregated form.



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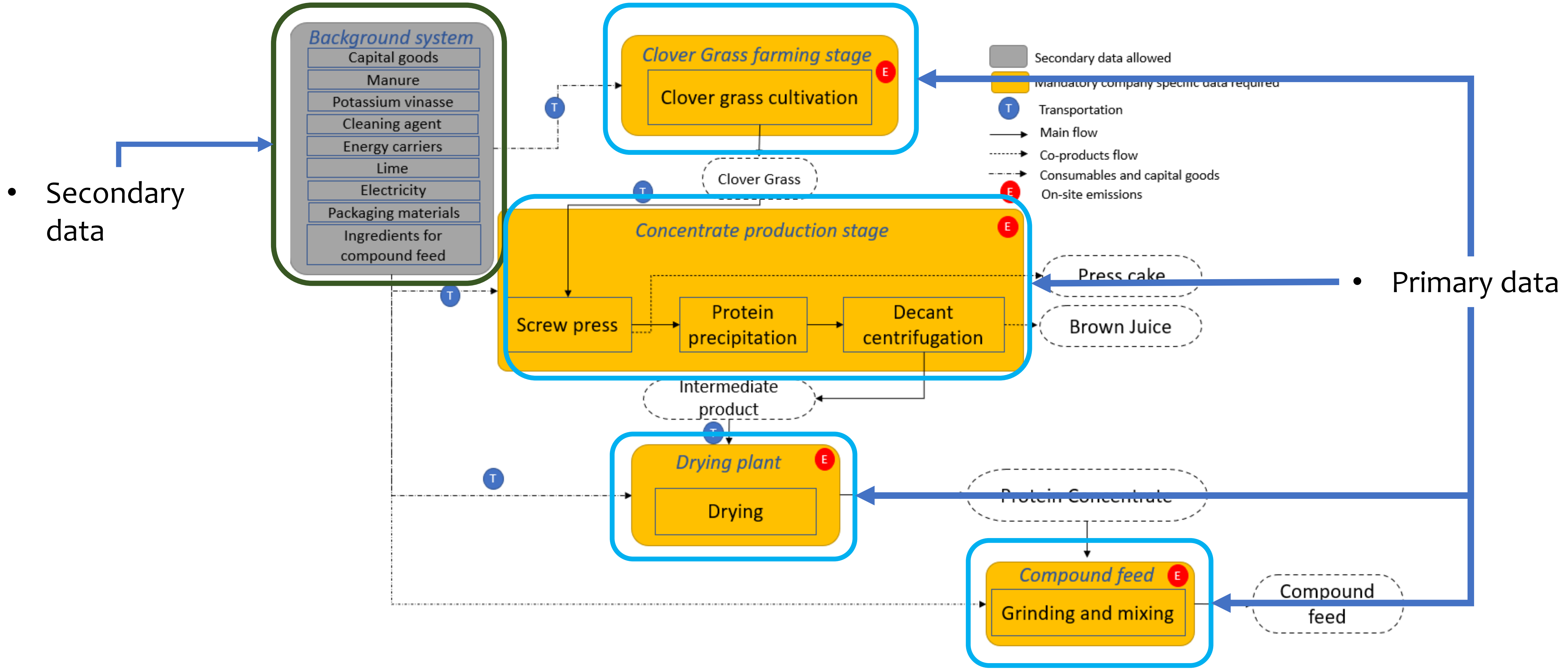
Data Source – Primary data vs. Secondary data



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Assessment requirements, modeling approach/assumptions

- Feed materials, additives, and pre-mixture materials
- Nutritional analysis
- Energy consumption in feed mill operation
- Inbound and outbound transportation

Parameters shown in Black color shall be provided and supplimented to PEF studies
Parameters shown in Green color are recommended to provided base on the following reference
http://www.feedipedia.org/

Main analysis	Unit	Avg	
Dry matter	% of feed weight		
Crude Protein	% DM		
Crude Fiber	% DM		
Ether Extract	% DM		
Ash	% DM		
Nitrogen	% DM (g/kg DM)		
Phosphorous	% DM (g/kg DM)		
Copper	% DM (g/kg DM)		
Zinc	% DM (g/kg DM)		
Calcium	% DM (g/kg DM)		
Magnesium	% DM (g/kg DM)		
Potassium	% DM (g/kg DM)		
etc.	% DM (g/kg DM)		
Starch (enzymatic)	MJ/kg DM		
Water-soluble carbohydrates	MJ/kg DM		
Gross energy	MJ/kg DM		
Gross calorific value	MJ/kg DM		
Energy digestibility	%		

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Compound Feed Formulation

- Two compound feed formulations for *egg-laying hens* are considered; Standard compound feed and compound feed with GPC.
- GPC contributes to 2% of the modified compound feed substituting part of the soybean meal in the standard feed.

Standard compound feed	Percentage (%)	Unit	Compound feed with GPC	Percentage (%)	Unit
Corn	34.10%		Corn	23.24%	
Wheat	20.00%		Wheat	22.00%	
Sunflowercakes	10.00%		Sunflowercakes	10.00%	
rapeseed cakes	5.90%		rapeseed cakes	5.90%	
Wheat bran	5.90%		Wheat bran	6.00%	
Fishmeal	5.40%		Fishmeal	5.00%	
Oats	5.00%		Oats	15.00%	
Soycakes	4.70%		Soycakes	2.00%	
Grass Protein Concentrate	**Na**		Grass Protein Concentrate	2.01%	
chalk	7.38%		chalk	7.30%	
Vitamins/minerals etc.	1.62%		Vitamins/minerals etc.	1.55%	
Electricity	0.088	kWh/kg compound feed	Electricity	0.088	kWh/kg compound feed
Heat	0.037	kWh/kg compound feed	Heat	0.037	kWh/kg compound feed

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Limitations

- PEF-compliant secondary datasets on organic ingredients for organic compound feeds.
  - Modeling approach: PEF on compound feed was done a practice while the results cannot be further used or interpreted for organic compound feeds.

- For comparative studies, a cradle-to-gate study *may not necessarily be sufficient* to capture all potential consequences.
  - **Situation 1:** the nutritional value or composition of the feed changes in a way that affects the production performance of food producing animals.
  - **Situation 2:** the chemical composition of the feed changes so that it affects the environmental performance of the farming systems where the feed is consumed.
  - Modeling approach: We assumed that two feed compounds would have similar responses in animals (or insignificant differences).

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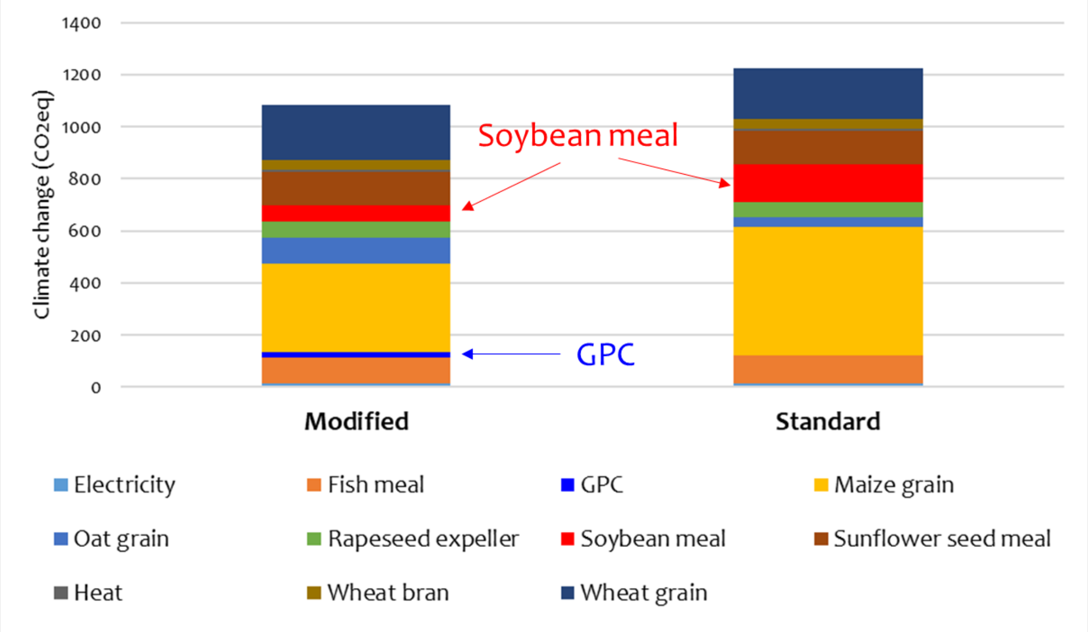
PEF of compound feed with/without GPC

Impact category	Reference unit	Standard compound feed	Compound feed with GPC	Difference
Acidification	mol H+ eq	11.86	12.02	1.30%
Climate change	kg CO2 eq	1222.32	1084.77	-12.68%
Climate change-Biogenic	kg CO2 eq	32.87	28.53	-15.19%
Climate change-Fossil	kg CO2 eq	1019.46	949.89	-7.32%
Climate change-Land use and land use change	kg CO2 eq	169.99	106.35	-59.84%
Ecotoxicity, freshwater	CTUe	29606.75	25552.58	-15.87%
Eutrophication marine	kg N eq	9.64	9.71	0.78%
Eutrophication, freshwater	kg P eq	0.20	0.20	0.26%
Eutrophication, terrestrial	mol N eq	47.77	47.62	-0.30%
Human toxicity, cancer	CTUh	3.92E-05	3.71E-05	-5.63%
Human toxicity, non-cancer	CTUh	1.32E-03	1.36E-03	3.04%
Ionising radiation, human health	kBq U-235 eq	71.97	63.29	-13.71%
Land use	Pt	231103.89	232284.99	0.51%
Ozone depletion	kg CFC11 eq	1.10E-05	3.19E-05	65.44%
Particulate Matter	disease inc.	1.15E-04	1.07E-04	-7.47%
Photochemical ozone formation - human health	kg NMVOC eq	3.35	3.02	-10.86%
Resource use, fossils	MJ	11000.51	9992.34	-10.09%
Resource use, minerals and metals	kg Sb eq	4.65E-03	4.05E-03	-14.88%
Water use	m3 depriv.	5419.83	6300.18	13.97%

- In 12 out of 19 impact categories, including climate change, compound feed with GPC had lower environmental footprint.
- The Climate change impact of compound feed with GPC was 12.7% lower than standard feed.



- Other feed ingredients, including maize grain, wheat grain, and sunflower seed meal are the main contributors to the environmental footprint of compound feed with GPC.

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Unseen aspects in PEF studies

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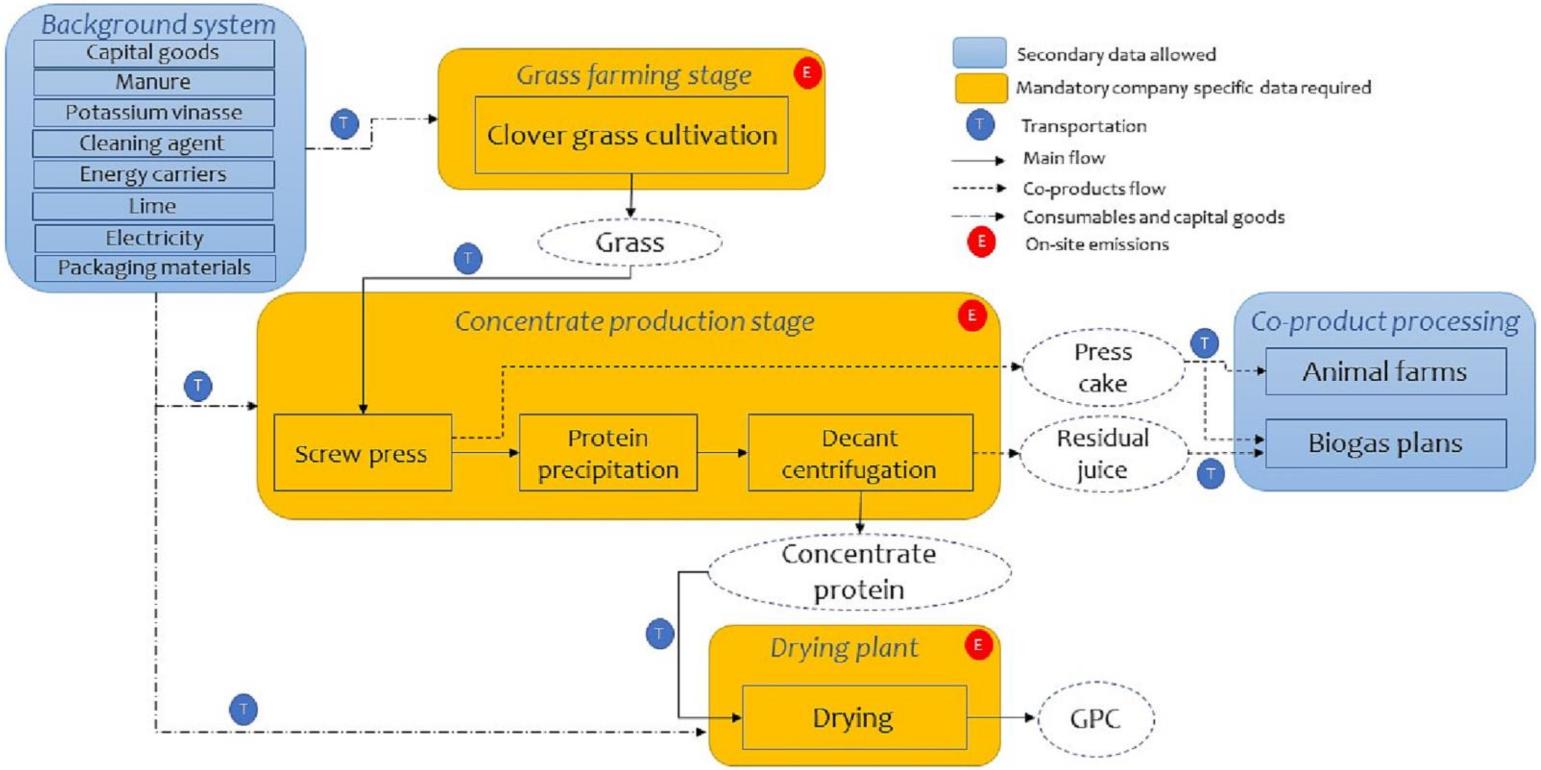
Remaining gaps from PEF studies

- Final use of side streams (i.e., brown juice and press fiber) is not accounted for due to economic allocation for by-products.

- Carbon sequestration is not included



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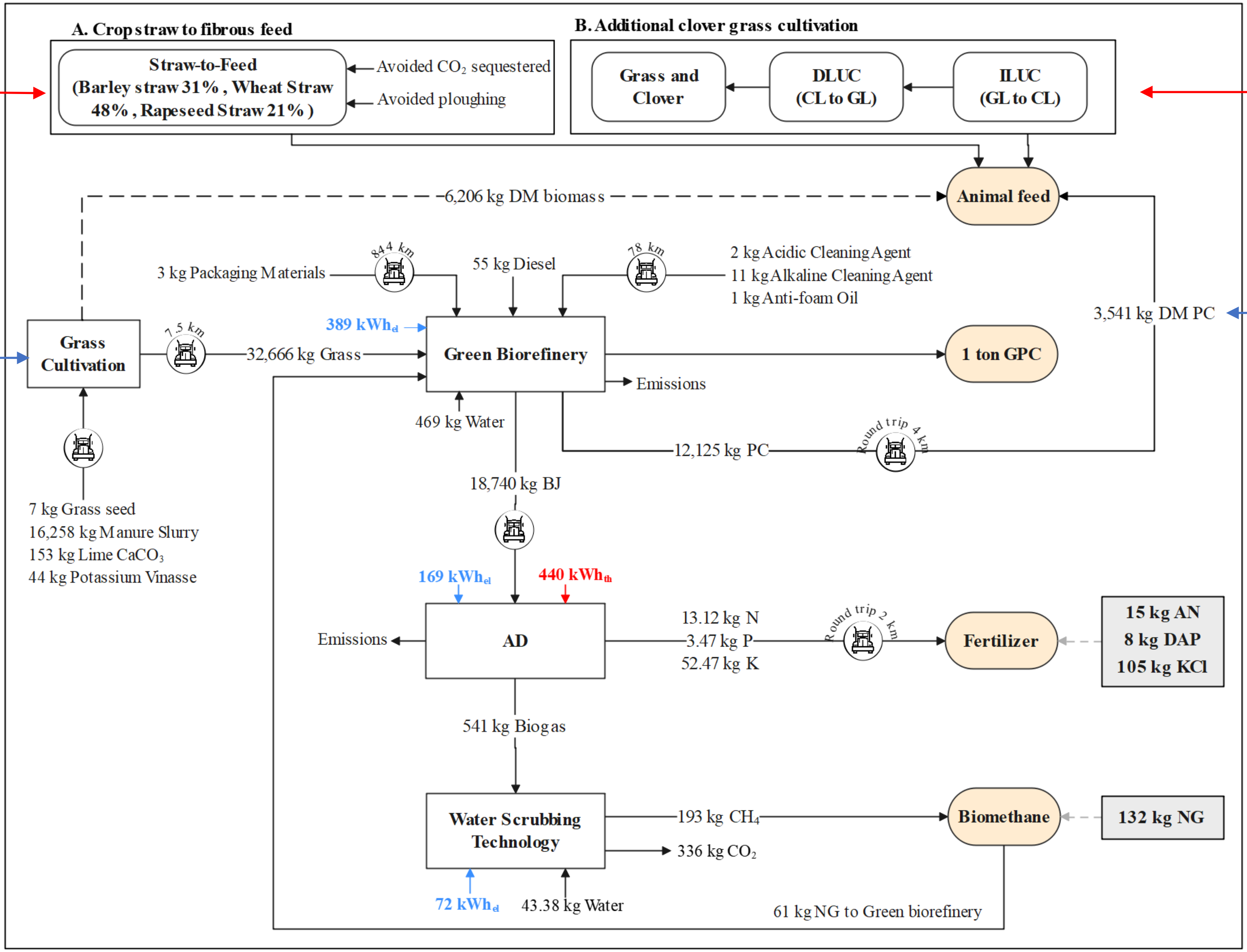
GWP: 1873 kg $CO_{2,eq}$/ton GPC

- Bulky materials for animal feed



GWP: 903 kg $CO_{2,eq}$/ton GPC

- Press cake used as bulky material for animal feed

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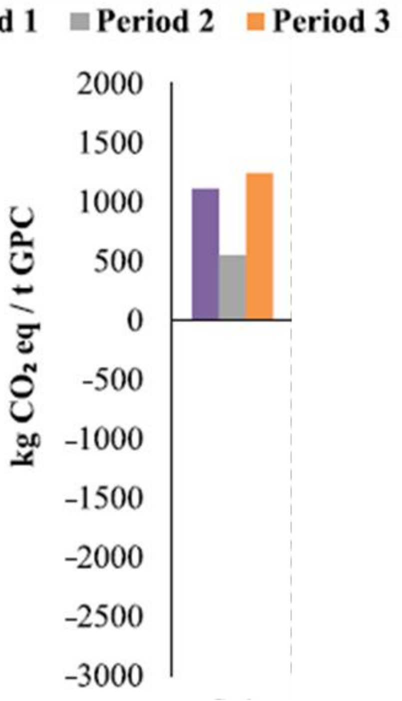
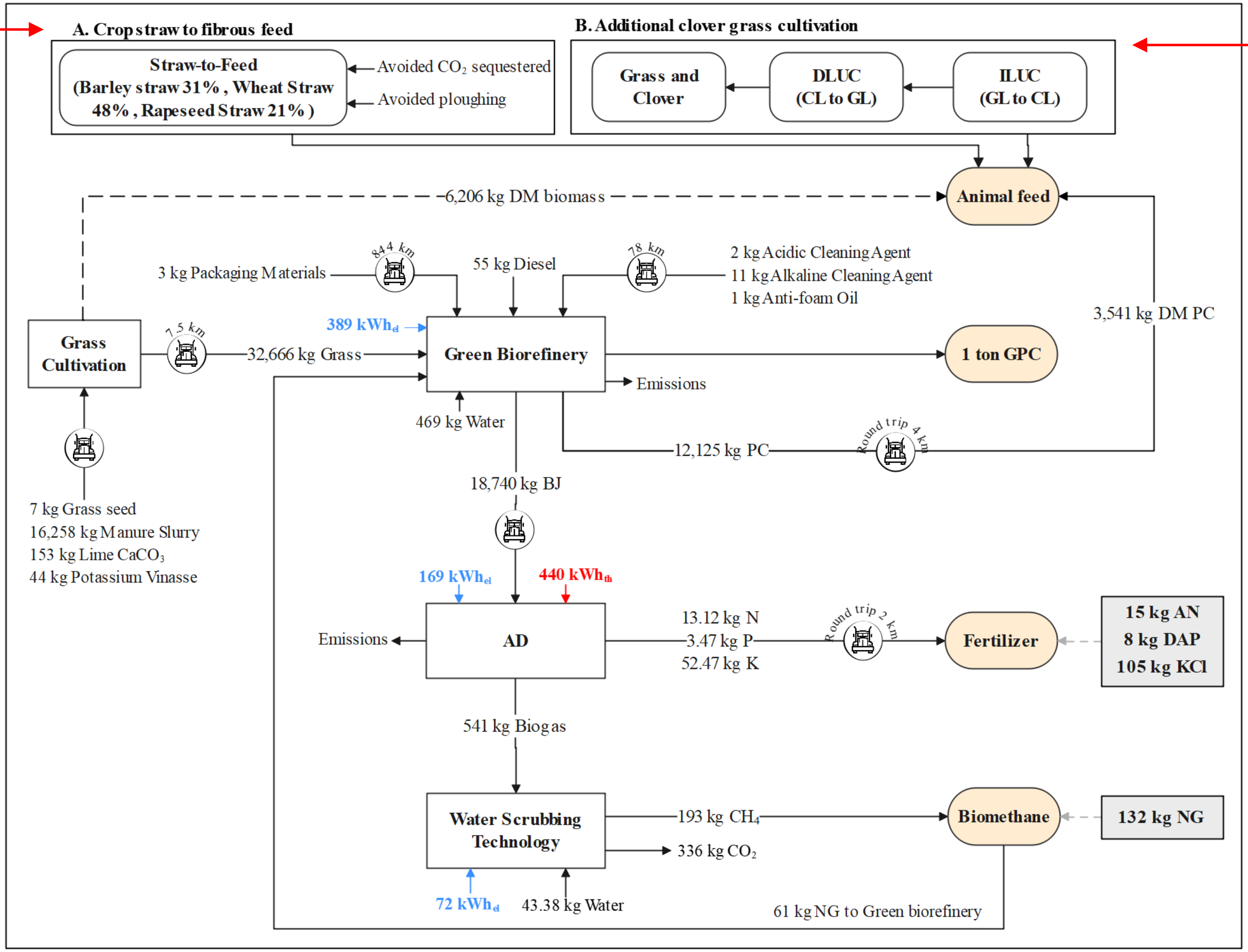
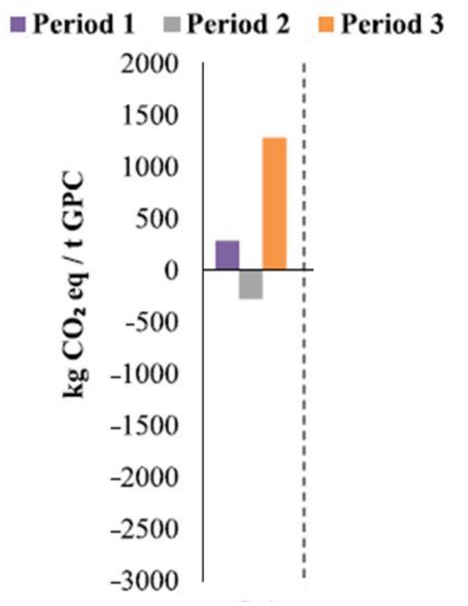
- **Carbon sequestration:**
- First 20 years of land transformation
  - First 15 years: 0.27 Mg-C per ha per year https://doi.org/10.1038/s41467-019-08636-w
  - 15 to 20 years: 0.47 Mg-C per ha per year
- After 20 years: No sequestration due to new carbon balance in the soil







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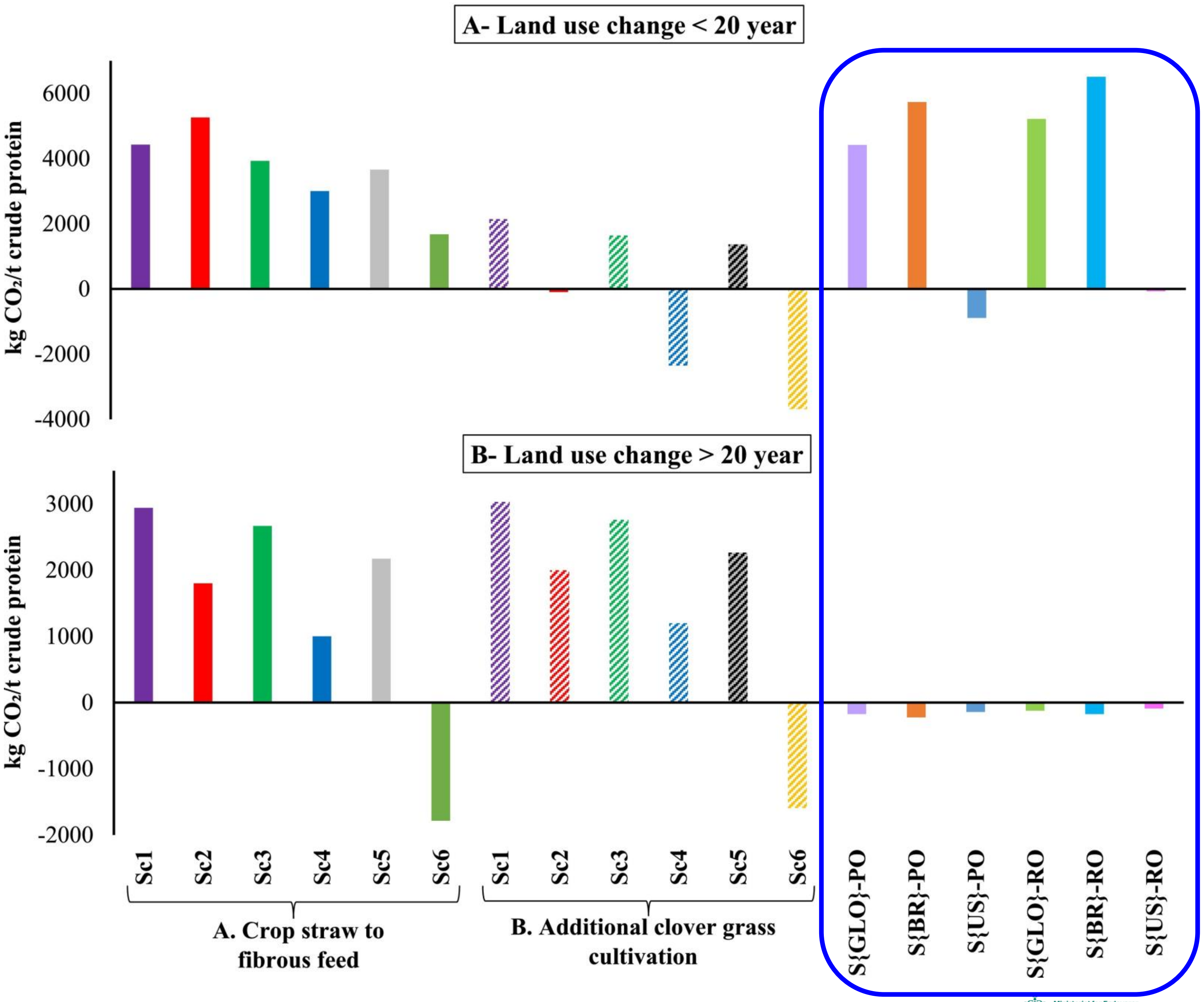
- A comparative analysis of global warming potential associated with clover grass protein concentrate and soybean meal, based on **1 tonne of crude protein** from each source.
- The assessment considers land use change impacts for the **1. first 20 years** and **2. after 20 years**.
- S stands for soybean meal; PO stands for soybean meal in loop with palm oil. RO stands for soybean meal in loop with rapeseed oil.



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Key findings of the consequential LCA

- PEF study showed that organic clover grass protein produced by a biorefinery in DK has lower EIs than average soy and soybean meal production.
- The environmental sustainability of protein concentrate from leafy biomass will depend on use of side streams, market mechanisms, and land transformation.
- The environmental sustainability of alternative feed protein sources shall be assessed based on different temporal scope and under various future socio-economic changes.

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PEF outlooks within feed protein market

1. PEF certification (requirements and challenges)
2. PEF tool
3. Digital passport for PEF certified products such as grass protein concentrate and compound feeds
4. Alignment with GFLI carbon footprint model
5. PEF of protein concentrate produced from other leafy biomass

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Using the product environmental footprint to strengthen the green market for sustainable feed ingredients; Lessons from a green biomass biorefinery in Denmark

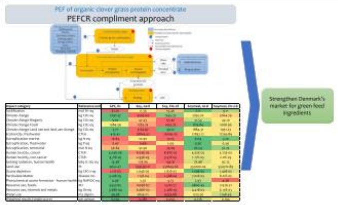
Benyamin Khoshnevisan [a,*], Erik Fog [b], Samin Baladi [d], Shealtiel William S. Chan [a,c], Morten Birkved [a]

[a] Department of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark, Denmark
[b] Innovation Centre for Organic Farming, ICOEL, Denmark
[c] School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Philippines
[d] Department of Biosystems Engineering, Faculty of Agriculture, Shahid Chamran University of Ahvaz, Ahvaz, Iran

HIGHLIGHTS

- Product Environmental Footprint was used as eco-labeling for a novel feed protein.
- Grass Protein Concentrate can substitute conventional protein sources.
- GPC had a climate change impact of 1091.5 kg $CO_{2,eq}$/tonne.
- Farming stage and emissions from manure dominated overall impacts.
- PEF showed huge potential for environmental declaration of products.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Jacopo Bacenetti

Keywords:
Product environmental footprint
Feed protein
Grass protein concentrate
Eco-labelling
Biomass biorefining

ABSTRACT

Finding new and sustainable proteinaceous feed ingredients, especially those produced from locally available resources, is at the top of the agenda of many countries, including Denmark, to become feed protein self-sufficient. Protein concentrate (PC) production via the biorefining of green biomass has attracted considerable interest in recent years since they are more land efficient and productive than soybeans. The biorefining of clover-grass into protein concentrate (GPC) is a promising substitute for soybean and soybean meal, however, the environmental impacts of GPC have not been studied. The Product Environmental Footprint (PEF) method, developed by EU Joint Research Centre for the "Single Market for Green Products Initiative" was employed to assess the environmental footprints of organic GPC. The instructions, methodology, and guidelines detailed in Product Environmental Footprint Category Rules (PEFCR) Feed for Food-Producing Animals were followed to implement this PEF study. The results were intended for in-house management, process improvement, early guidance on the environmental footprint (EF) of compound feeds containing GPC, and the EF of livestock and animal production whose feed ration contains GPC. Our results showed that GPC would have a climate change impact of 1091.47 kg CO_2,eq/t GPC. We found that farming/cultivation, more specifically direct emissions from manure slurry, dominated most impact categories, including acidification and eutrophication. The results were found sensitive to the choice of allocation method and very case-specific. For instance, the climate change impact of GPC was higher under economic allocation than direct substation, but the acidification impact was lower in economic allocation than direct substitution. However, the direct substitution method,

* Corresponding author.
E-mail address: bekh@igt.sdu.dk (B. Khoshnevisan).

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Environmental impacts of a novel biorefinery platform integrated with power-to-protein technology to decrease dependencies on soybean imports

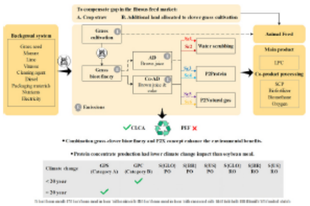
Shealtiel William S. Chan [a,b,c], Hadis Marami [a,d,*], Lemmuel L. Tayo [b,e,**,***], Erik Fog [f], Thalles A. Andrade [g,h], Morten Ambye-Jensen [g,h], Morten Birkved [a], Benyamin Khoshnevisan [a]

[a] Department of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark, Denmark
[b] School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Manila 1002, Philippines
[c] School of Graduate Studies, Mapua University, Manila 1002, Philippines
[d] Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran
[e] Department of Biology, School of Medicine and Health Sciences, Mapua University, Makati 1200, Philippines
[f] Innovation Centre for Organic Farming, ICOEL, Denmark
[g] Aarhus University Centre for Circular Bioeconomy, Aarhus University, Viborg, Denmark
[h] Department of Biological and Chemical Engineering, Aarhus University, Aarhus, Denmark

HIGHLIGHTS

- Sustainable use of side streams under multiple scenarios, including P2X was assessed.
- Grass cultivation had the highest impact on all developed scenarios.
- CLCA study can produce policymaking decisions for the importation of soy products.
- Clover grass protein is an environmentally sustainable alternative to soybean meal.
- Integrating a green biorefinery with P2Protein enhances environmental benefits.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Jacopo Bacenetti

Keywords:
Leaf protein concentrate
Biomass biorefining
Protein self-sufficiency
Life cycle assessment
Nutrient extraction

ABSTRACT

The consistent population growth is directly tied to the annual rise in livestock production, placing a substantial burden on the crop sector that supplies animal feed. The Danish government has been relying on importing soybeans and soybean meal to be used as animal feed. However, this sparked environmental concerns that require more environmentally friendly solutions, such as self-sufficiency in animal feed production. The rise of green biorefineries allows new avenues of animal proteinaceous feed production using green biomass to produce leaf protein concentrate (LPC) and utilize side-stream products, such as brown juice and press cake, for feed-quality products. This study evaluated the combination of grass-clover biorefinery and the power-to-X

* Correspondence to: H. Marami, Department of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark, Denmark.
** Correspondence to: L.L. Tayo, School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Manila 1002, Philippines.
*** Correspondence to: L.L. Tayo, Department of Biology, School of Medicine and Health Sciences, Mapua University, Makati 1200, Philippines.
E-mail addresses: hmar@igt.sdu.dk (H. Marami), lltayo@mapua.edu.ph (L.L. Tayo).

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Supplementary information

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nature COMMUNICATIONS

https://doi.org/10.1038/s41467-019-08636-w

ARTICLE

https://doi.org/10.1038/s41467-019-08636-w OPEN

Soil carbon sequestration accelerated by restoration of grassland biodiversity

Yi Yang[1], David Tilman[1,2], George Furey[1] & Clarence Lehman[1]

Agriculturally degraded and abandoned lands can remove atmospheric CO_2 and sequester it as soil organic matter during natural succession. However, this process may be slow, requiring a century or longer to re-attain pre-agricultural soil carbon levels. Here, we find that restoration of late-successional grassland plant diversity leads to accelerating annual carbon storage rates that, by the second period (years 13–22), are 200% greater in our highest diversity treatment than during succession at this site, and 70% greater than in mono-cultures. The higher soil carbon storage rates of the second period (years 13–22) are associated with the greater aboveground production and root biomass of this period, and with the presence of multiple species, especially C4 grasses and legumes. Our results suggest that restoration of high plant diversity may greatly increase carbon capture and storage rates on degraded and abandoned agricultural lands.

[1]Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, MN 55108, USA. [2]Bren School of Environmental Science and Management, University of California, Santa Barbara, CA 93106, USA. Correspondence and requests for materials should be addressed to D.T. (email: tilman@umn.edu)

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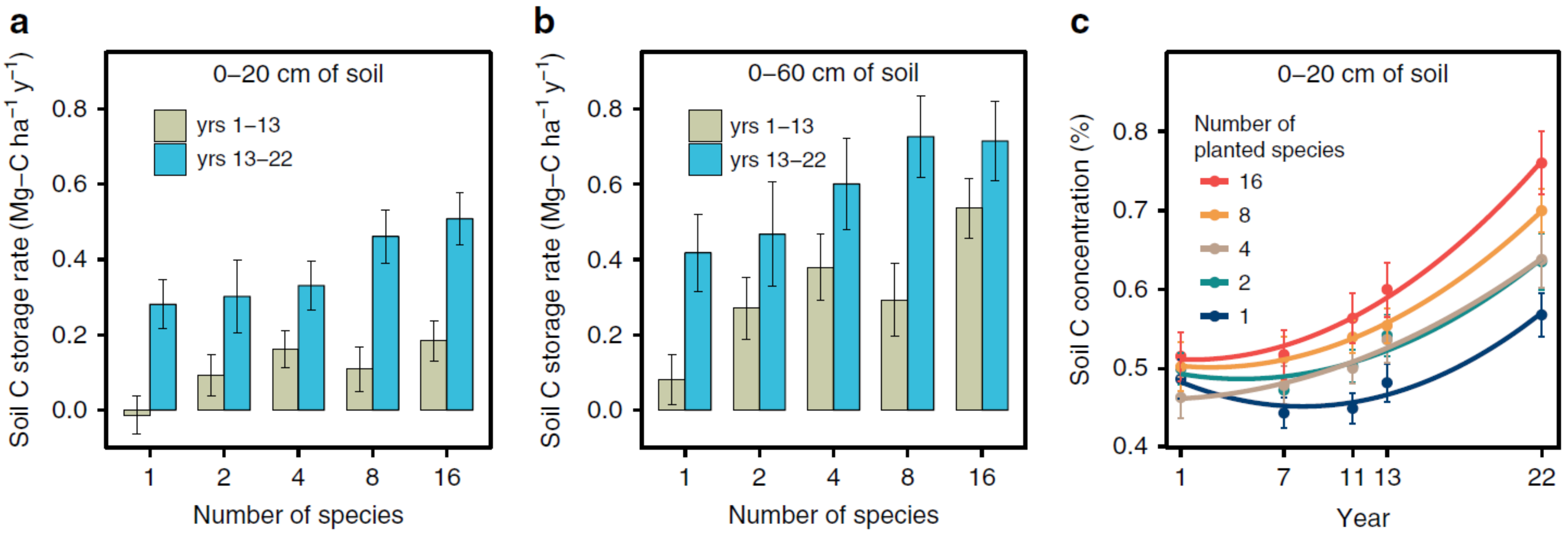

Fig. 1 Change in soil C over 22 years. **a**, **b** Average annual soil C storage rates over years 1-13 (green bars) and years 13–22 (blue bars) in upper 20 cm of soil (**a**) and in upper 60 cm (**b**) (Supplementary Table 1). Bars are means with standard errors. **c** Dynamics of soil C concentration in upper 20 cm of soil for plots planted with 1, 2, 4, 8, or 16 perennial grassland species (Supplementary Table 2). Dots are means with standard errors; fitted curves are quadratic

- The **average annual rate of C storage** in soils, as quantified by ΔC/Δt (units of Mg of C ha–1 y–1), was **greater in the second period (13–22 years)** of the experiment than in the first period (1–13 years; Fig. 1a, b).
- These accelerating rates of soil C sequestration were apparent for both the 0–20 cm depth soil profile

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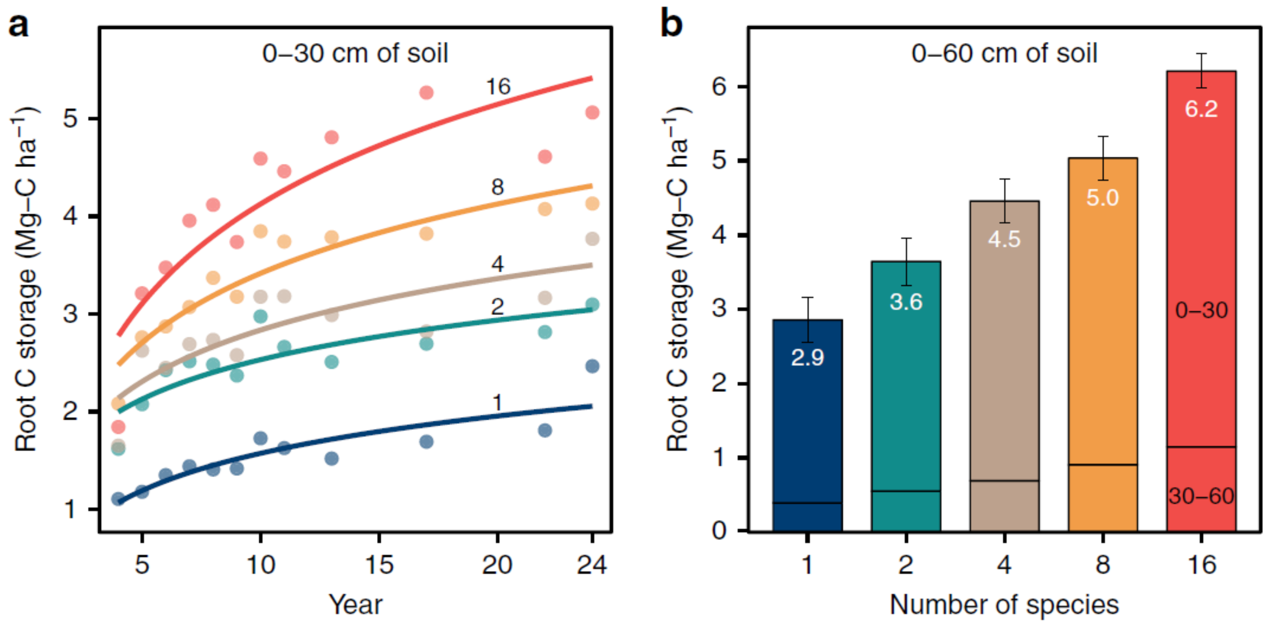

Fig. 2 Change in root C over 24 years. **a** Change in root C in upper 30 cm of soil under different experimentally imposed levels of plant species diversity. Dots indicate mean root C at a given year; curves fitted with log functions; the number on each curve indicates plant species diversity. **b** Total root C storage after 24 years of growth in upper 60 cm of soil. Numbers in white indicate mean total root C storage, error bars indicate standard errors, and numbers in black indicate soil depth increments (cm)

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Supplementary materials

Title:

Environmental impacts of a novel biorefinery platform integrated with power-to-protein technology to decrease dependencies on soybean imports

Authors:

Shealtiel William S. Chan[a,b,c], Hadis Marami[a,*], Lemmuel L. Tayo[b,d,*], Erik Fog[e], Thalles A. Andrade[f,g], Morten Ambye-Jensen[f,g], Morten Birkved[a], Benyamin Khoshnevisan[a]

Affiliations:

[a] Department of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark

[b] School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Manila 1002, Philippines

[c] School of Graduate Studies, Mapua University, Manila 1002, Philippines

[d] Department of Biology, School of Medicine and Health Sciences, Mapua University, Makati 1200, Philippines

[e] Innovation Centre for Organic Farming, ICOEL, Denmark

[f] Aarhus University Centre for Circular Bioeconomy, Aarhus University, Viborg, Denmark

[g] Department of Biological and Chemical Engineering, Aarhus University, Aarhus, Denmark

[*,**] **Corresponding authors:**

Hadis Marami

Department of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark

Email: hmar@igt.sdu.dk

Lemmuel L. Tayo

School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Manila 1002, Philippines

Department of Biology, School of Medicine and Health Sciences, Mapua University, Makati 1200, Philippines

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Environmental impacts of a novel biorefinery platform integrated with power-to-protein technology to decrease dependencies on soybean imports

Shealtiel William S. Chan[a,b,c], Hadis Marami[a,d,*], Lemmuel L. Tayo[b,e,**,***], Erik Fog[f], Thalles A. Andrade[g,h], Morten Ambye-Jensen[g,h], Morten Birkved[a], Benyamin Khoshnevisan[a]

[a] *Department of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark, Denmark*
[b] *School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Manila 1002, Philippines*
[c] *School of Graduate Studies, Mapua University, Manila 1002, Philippines*
[d] *Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran*
[e] *Department of Biology, School of Medicine and Health Sciences, Mapua University, Makati 1200, Philippines*
[f] *Innovation Centre for Organic Farming, ICOEL, Denmark*
[g] *Aarhus University Centre for Circular Bioeconomy, Aarhus University, Viborg, Denmark*
[h] *Department of Biological and Chemical Engineering, Aarhus University, Aarhus, Denmark*

HIGHLIGHTS

- Sustainable use of side streams under multiple scenarios, including P2X was assessed.
- Grass cultivation had the highest impact on all developed scenarios.
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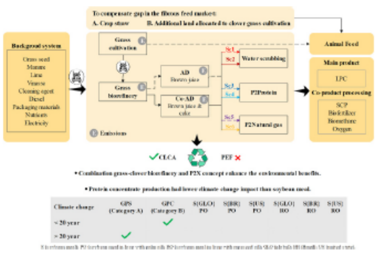
GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Jacopo Bacenetti

Keywords:
Leaf protein concentrate
Biomass biorefining
Protein self-sufficiency
Life cycle assessment
Nutrient extraction

ABSTRACT

The consistent population growth is directly tied to the annual rise in livestock production, placing a substantial burden on the crop sector that supplies animal feed. The Danish government has been relying on importing soybeans and soybean meal to be used as animal feed. However, this sparked environmental concerns that require more environmentally friendly solutions, such as self-sufficiency in animal feed production. The rise of green biorefineries allows new avenues of animal proteinaceous feed production using green biomass to produce leaf protein concentrate (LPC) and utilize side-stream products, such as brown juice and press cake, for feed-quality products. This study evaluated the combination of grass-clover biorefinery and the power-to-X

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Table SI-1. Agricultural Land Occupied and Harvested by Alfalfa (Lucerne), Clover, and Temporary Grass for the Year 2022 (Statistics Denmark, 2022).

Cultivated Area by Unit, Region, Time, and Crop			
	Unit	**Alfalfa (Lucerne)**	**Temporary Grass and Clover**
All of Denmark	Hectares	513	269,610
Harvest by Unit, Region, Time, and Crop			
All of Denmark	Million kg	31.5	13,905.4

Table SI-10. Total agricultural and horticultural land and land allocation for Alfalfa, Temporary Grass and Clover.

	Total Agricultural and Horticultural Land	Land allocated to Alfalfa or Lucerne	Land allocated to Temporary Grass and Clover	Unit
All of Denmark	2,624,245	513	269,610	ha
Percentage	100	0.02	10.27	%

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https://doi.org/10.1007/s10887-018-9159-1

CrossMark

Agricultural productivity and economic development: the contribution of clover to structural transformation in Denmark

Torben Dall Schmidt[1] · Peter Sandholt Jensen[1] · Amber Naz[1]

Published online: 30 August 2018

Abstract
This paper contributes to the debate on the impact of agricultural productivity on long run economic development. It presents evidence that widespread adoption of clover contributed to local economic development based on a panel of 56 Danish market towns. We adopt a differences-in-differences approach augmented by an instrumental variable and find that the adoption of clover accounts for about 8 percent of the growth in market town population from 1672 to 1901. The analysis suggests that the effect of the adoption of clover on the process of development was mediated by its impact on human capital formation.

Keywords Agricultural productivity · Clover · Urbanization

JEL Classification N1 · N9 · O1 · O4 · R11

1 Introduction

Whether and how agricultural productivity influences long run development is an important question in the literature on growth and development (e.g. Schultz 1953; Lewis 1954; Rostow 1960). Theoretically, increased agricultural productivity would stimulate the transition to a modern, industrial economy in the context of a closed economy. Yet, in open economies

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✉ Peter Sandholt Jensen
psj@sam.sdu.dk

Torben Dall Schmidt
tds@sam.sdu.dk

Amber Naz

Danish economic historians (Lampe and Sharp forthcoming). Clover may increase agricultural productivity in two principal ways. First, clover serves to increase nitrogen supply in the soil, which increases crop yields (e.g. Kjærgaard 1995). In fact, the supply of nitrogen governs the yields of crops, such as wheat, barley, and rye, when they have enough water.[3] Second, clover provides excellent animal fodder, which allows for a larger cattle population and an increased production of milk and butter.

Forside

Eksamensinformation
T220014102 - T220014102: Master Thesis - 40 ects,
Tristan Fonck

Besvarelsen afleveres af
Tristan Fonck
trfon21@student.sdu.dk

Eksamensadministratorer
Tina Carøe Sørensen
tcs@tek.sdu.dk
+4565507360

Bedømmere
Morten Birkved
Eksaminator
morb@igt.sdu.dk
+4565507636

Benyamin Khoshnevisan
Eksaminator
bekh@igt.sdu.dk
+4565507526

Simon Bruhn
Eksaminator
simb@igt.sdu.dk
+4565507420

Ole Leinikka Dall
Censor
ole@dall.dk
+4521441480

Besvarelsesinformationer

Titel: An Outlook on the Danish Agricultural Consumption and Flows for 2050
Titel, engelsk: An Outlook on the Danish Agricultural Consumption and Flows for 2050
Indeholder besvarelsen fortroligt materiale: Ja

2019	Produced (t)	Harvest index	Imported	Exported	For field	For food industry	Feeding	Import/export	Area (ha)	Yield (t/ha)	Residues	Utilised	Left
Cereals	9,629,800	45%	1,240,700	1,813,513	206,000	701,000	6,732,000	1,417,987	1,373,700	7	11,769,756	3,020,821	8,748,934
Roots, tubers	2,408,700	70%	172,647	201,312	131,072	2,359,200	291,000	- 401,237	266,744	9	1,032,300	-	1,032,300
Sugar crops	2,339,900	50%	154,112	162,017	127,328	22,918	283,000	1,898,749	259,125	9	2,339,900	738,028	1,601,872
Pulses	85,800	58%	37,788	42,666		27,922	53,000	-	22,200	4	62,131	4,700	57,431
Oil bearing crops	729,000	37%	402,219	97,870		1,033,349		-	165,500	4	1,241,270	87,300	1,153,970
Vegetables	301,562	50%	406,852	87,860		620,554		-	13,083	23	301,562	-	301,562
Fruits	41,650	65%	596,214	153,680		484,184		-	4,169	10	22,427	-	22,427
Maize for green fodder	7,422,400	85%	-	-	-	-	7,422,400		186,400	40	1,309,835	336,182	973,653
Cereals for green fodder	1,031,000	85%	-	-	-	-	1,031,000		25,200	18	181,941	46,697	135,244
Grass and clover	12,444,300	70%					12,444,300		285,700	44	5,333,271	-	5,333,271
Fodder sugar beet	323,300	50%					323,300		4,500	72	323,300	101,972	221,328
Totals	**36,757,412**		**3,411,769**	**5,875,654**	**464,400**	**5,249,127**	**28,580,000**		**2,320,621**		**23,917,694**	**4,335,700**	**19,581,993.7**

Ministeriet for Fødevarer, Landbrug og Fiskeri

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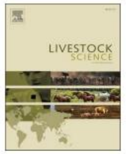

Biorefined press cake silage as feed source for dairy cows: effect on milk production and composition, rumen fermentation, nitrogen and phosphorus excretion and *in vitro* methane production

E. Serra[a,*], M.B. Lynch[b], J. Gaffey[c], J.P.M. Sanders[d], S. Koopmans[d], M. Markiewicz-Keszycka[a], M.H. Bock[a], Z.C. McKay[a], K.M. Pierce[a]

[a] School of Agriculture and Food Science, University College Dublin, Lyons Farm, Lyons Estate, Co. Kildare, Celbridge, Naas W23 ENY2, Ireland
[b] Teagasc, Crops, Environmental and Land-Use Programme, Johnstown Castle, Wexford, Ireland
[c] Circular Bioeconomy Research Group (CIRCBIO), Shannon Applied Biotechnology Centre, Munster Technological University, Dromtacker, Tralee V92 CX88, Ireland
[d] Grassa BV, Venlo, SZ 5928, The Netherlands

HIGHLIGHTS

- Press cake silage can partially replace grass silage in the diet of dairy cows.
- Press cake group maintained similar milk production to the grass silage only group.
- Experimental treatment improved nitrogen use efficiency.
- In the *in vitro* study the methane production was not affected by treatment.

ARTICLE INFO

Keywords:
Biorefinery
Dairy cow
Nitrogen
Phosphorus

ABSTRACT

The objective of this study is to investigate the effect of replacing grass silage with biorefined grass silage (press cake silage) on dry matter intake (DMI), milk production and composition, rumen fermentation parameters, nitrogen and phosphorus excretion of early lactation Holstein Friesian dairy cows. An *in vitro* experiment using the rumen simulation technique (RUSITEC) also investigated the *in vitro* dry matter disappearance and methane (CH_4) production of these feedstuffs. In this study, press cake silage was made from perennial ryegrass (*Lolium perenne*) using a novel biorefining process. Thirty early-lactation cows (*Bos taurus* strain Holstein Friesian) were used in a randomized complete block design experiment ($n = 15$) and offered two dietary treatments for a 56 d period: Grass silage (GS): 14 kg dry matter (DM) grass silage + 7.2 kg DM of concentrate + 0.44 kg DM of soyabean meal; Press cake (PC): 5 kg DM grass silage + 9 kg DM press cake silage + 7.2 kg DM concentrate + 0.44 kg DM soyabean meal. The dietary treatments were also incubated *in vitro* for a period of 18 days using the RUSITEC. In the *in vivo* study, DMI was lower for PC compared to GS. No difference was observed between the treatments for milk yield and milk quality; however, milk fat yield was lower and milk solids yield tended to be lower in PC compared to GS. Cows offered PC had higher N use efficiency (NUE, milk N/N intake), lower total N excretion and lower N excretion in feces and urine compared to cows offered GS. Total and fecal P excretion was lower in cows fed PC compared to cows fed GS. Ruminal NH_3-N concentration was lower when PC was offered. *In vitro* rumen fermentation parameters such as pH, volatile fatty acids and CH_4 output were not affected by treatment. *In vitro* dry matter disappearance and NH_3-N concentration were lower for PC compared to GS. This study suggests that press cake silage can partially replace grass silage in the diet of dairy cows with beneficial effects on the environment and without compromising animal productivity.

Table 1
Chemical composition (g/kg) of diets and ingredients.

Chemical composition (g/kg DM unless stated)	Diets		Experimental feedstuffs			
	GS[1]	PC[2]	Grass silage	Press cake silage	Standard concentrate	Soyabean meal
DM	411.8	486.3	299.4	374.1	900	880
Ash	100.4	67.5	98.3	42.0	69.2	86.6
Crude Protein	180.2	152.2	164.4	109.3	188.2	532.5
NDF[3]	373.3	569.4	490.9	740.9	153.5	75.4
ADF[4]	225.2	270.7	289.7	413.3	78.6	41.6
WSC[5]	46.2	42.0	42.6	35.6	NA[6]	NA
Starch	109.7	108.6	15.5	13.3	486.0	25.8
Phosphorus	4.6	4.3	4.2	3.6	6.1	7.0
AIA[7]	20.8	11.3	27.4	4.3	9.6	4.0
Ether extract	46.8	25.5	34.6	28.2	25.2	12.9
Gross energy (MJ/kg of DM)	17.98	18.15	17.65	18.30	17.70	19.60

[1]Grass silage treatment (14 kg DM of grass silage + 7.2 kg DM standard concentrate +0.44 kg DM soyabean meal).
[2]Press cake treatment (5 kg DM grass silage + 9 kg DM press cake silage + 7.2 kg DM standard concentrate + 0.44 kg DM soyabean meal).
[3]Neutral Detergent Fibre (NDF).
[4]Acid Detergent Fibre (ADF).
[5]Water Soluble Carbohydrate (WSC).
[6]Not analyzed (NA).
[7]Acid Insoluble Ash (AIA).

SDU

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Table 2
The effect of treatment on dry matter intake, feed efficiency, body condition score, body weight, milk production and milk composition.

Item	Treatment GS [1]	PC [2]	SEM	*P*-value
DMI				
PMR [3] (kg DM/d)	15.73	14.40	0.342	0.01
Total (kg DM/d)	19.33	18.00	0.342	0.01
Feed efficiency [4]	1.31	1.27	0.024	0.24
DMD (%) [5]	70.75	72.00	0.871	0.31
Start BCS	2.97	2.93	0.069	0.74
End BCS	2.91	2.86	0.058	0.55
BCS change	-0.05	-0.06	0.053	0.83
Start BW (kg)	651.63	647.8	21.095	0.89
End BW (kg)	663.17	654.33	19.183	0.74
BW change (kg)	11.53	6.53	14.522	0.80
Milk production (kg/d)				
Milk yield	28.02	27.33	0.724	0.51
Fat	1.28	1.18	0.031	0.03
Protein	0.97	0.94	0.019	0.34
Milk solids	2.24	2.11	0.046	0.05
Lactose	1.23	1.21	0.027	0.71
Casein	0.75	0.74	0.015	0.41
Milk composition %				
Fat	4.58	4.35	0.133	0.24
Protein	3.47	3.44	0.071	0.79
Lactose	4.47	4.49	0.014	0.35
Casein	2.79	2.76	0.055	0.72
Urea (g/100g of milk)	0.027	0.024	0.0007	0.01
SCC (x 10^3 cells/mL) [6]	27	29	3.613	0.06
ECM (kg) [7]	24.94	23.33	0.044	0.04

[1] Grass silage treatment (14 kg DM of grass silage + 7.2 kg DM standard concentrate +0.44 kg DM soyabean meal).
[2] Press cake treatment (5 kg DM grass silage + 9 kg DM press cake silage + 7.2 kg DM standard concentrate + 0.44 kg DM soyabean meal).
[3] Partial mixed ration.
[4] Feed efficiency = kg of ECM/kg of DMI.
[5] Apparent total tract dry matter digestibility (DMD).
[6] For SCC, data was transformed by conducting a Box-Cox transformation analysis to calculate *P*-value. The corresponding least squares means and standard errors of the non-transformed data are presented in results for clarity.
[7] Energy Corrected Milk (ECM) = [(0.03273 × milk yield kg) + (7.65 × milk protein kg) + (12.97 × milk fat kg)].

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