Alfalfa to get back into planetary boundaries

2025 world alfalfa congress
FRANCE REIMS-CHÂLONS

Session 5
Alfalfa-based cropping systems in sustainable land-use for livestock production

Session chair(s): Liu N. & Labanca H.

Plenary session

FROM 03 › TO 06 nov. 2025

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Environmental footprint assessment of alfala-based dried forage in Italy: life cycle analysis, quantification of impacts and environmental benefits

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UNIVERSITÀ DI BOLOGNA

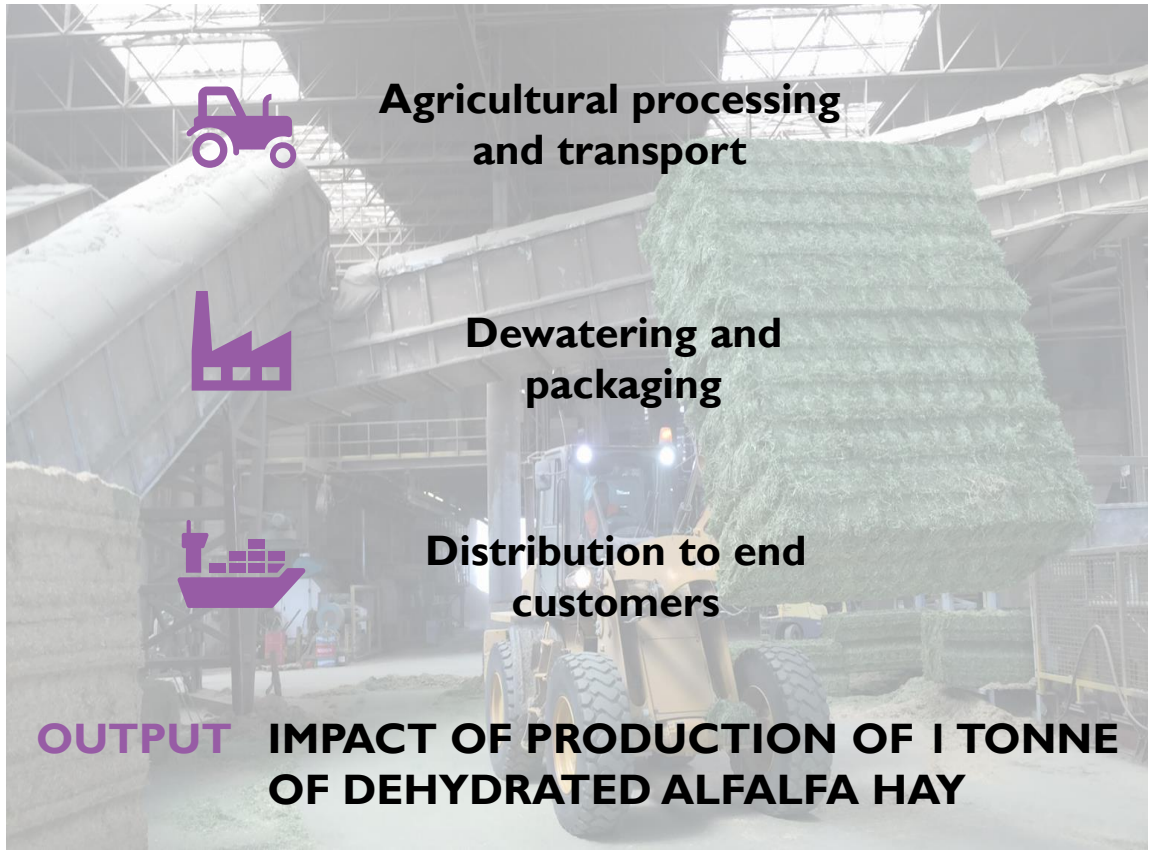
TURTLE

AIFE

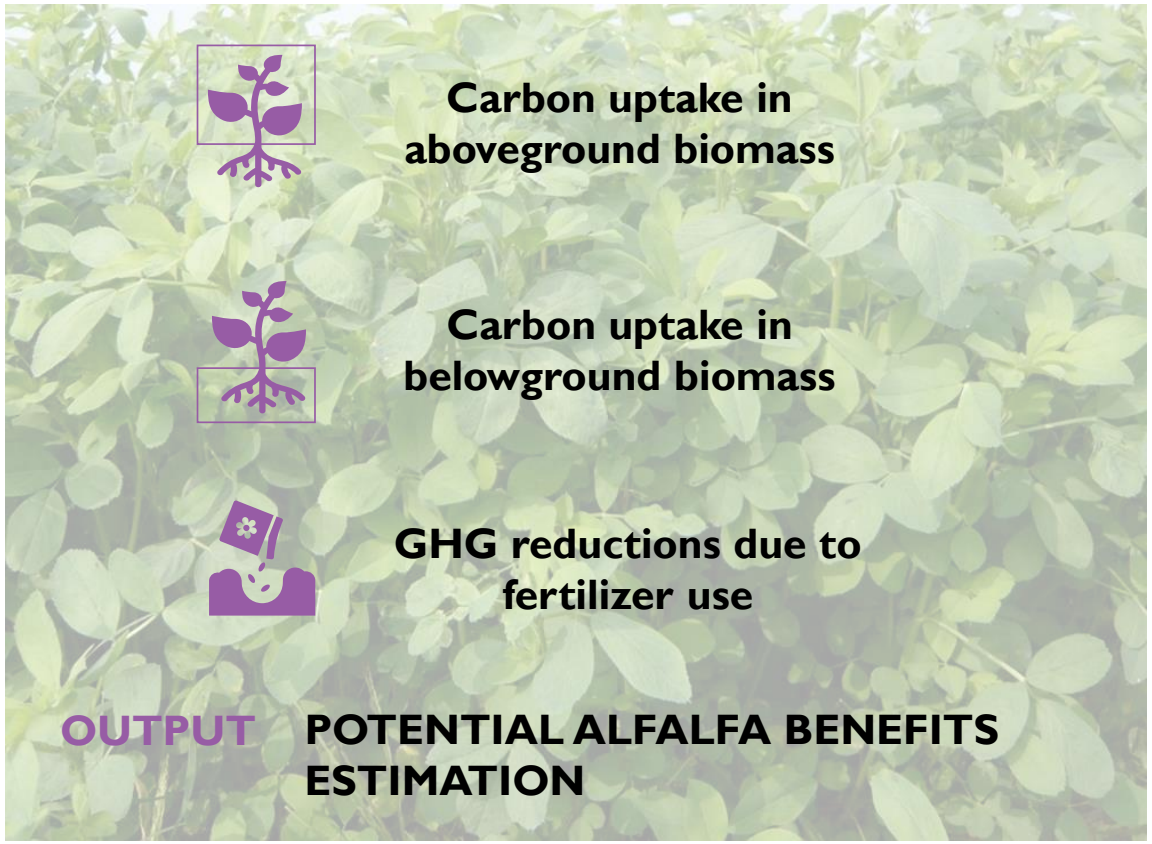
FROM 03 TO 06 nov. 2025

Goal and scope of the study

GOAL 1 – Environmental impact analysis of alfalfa forage production in Italy



GOAL 2 – Evaluation of the potential benefits of growing alfalfa



Materials and methods: GOAL 1

Life Cycle Assessment (ISO14040/44)

European Commission, 2018. PEF Guidance

LCA Software

SET UP OF THE LCA STUDY

F.U. Definition

1 ton of products (88% dry mass)

Made Green in Italy PCR (MASE, Gov. Italy)

Companies sampling

5/23 companies selected (20-23% share of production)

EU PEF recommendation 2021/2279

COLLECTION OF INPUTS

Seeds | Fertilizer | Diesel | Electricity | Natural gas | Transport | Packaging

DEFINITION OF PROCESSES

Agricultural processing

Transport from field to facility

Drying and packaging

Distribution to customers

CALCULATION OF IMPACT INDICATORS

Impact Category	Unit	Abbreviation
Climate change	kg CO_2 eq	CC
Ozone depletion	kg CFC11 eq	OD
Ionising radiation	kBq U-235 eq	IR
Photochemical ozone formation	kg NMVOC eq	POD
Particulate matter	disease inc.	PM
Human toxicity, non-cancer	CTUh	HTnon-c
Human toxicity, cancer	CTUh	HTc
Acidification	mol H^+ eq	AC
Eutrophication, freshwater	kg P eq	EUf
Eutrophication, marine	kg N eq	EUm
Eutrophication, terrestrial	mol N eq	EUt
Ecotoxicity, freshwater	CTUe	ECT
Land use	Pt	LU
Water use	m^3 depriv.	WU
Resource use, fossils	MJ	RDf
Resource use, minerals and metals	kg Sb eq	RDm

EF 3.0 Midpoint Indicators

Materials and methods: GOAL 2

THEORETICAL DEVELOPMENT OF EQUATIONS

CO_2 uptake in abovegorund biomass

$$Uptake_{aCO_2} = Y_{dm}/HI \times CF \times CO_{2_{MW}}$$

$Y_{dm} = dry\ matter\ yield\ [ton\ ha^{-1}year^{-1}]$

$HI = harverst\ index\ [dimensionless]$

$CF = carbon\ fraction\ in\ biomass\ [dimensionless]$

$CO_{2_{MW}} = molecular\ weight\ ratio\ [dimensionless]$

ISPRA, 2022;
Simon Eggleston and Michael Walsh, 2006;
Olson, 1983;
Eve et al., 2014

CO_2 uptake in belowground biomass

$$Uptake_{bCO_2} = Y_{peak}/HI \times CF \times R{:}S \times CO_{2_{MW}}$$

$Y_{peak} = peak\ production\ value\ (single\ cut)\ [ton\ ha^{-1}]$

$HI = harverst\ index\ [dimensionless]$

$CF = carbon\ fraction\ in\ biomass\ [dimensionless$

$R{:}S = Root{:}Shoot\ index\ [dimensioless]$

$CO_{2_{MW}} = molecular\ weight\ ratio\ [dimensionless]$

Bortolazzo et al., 2016;
Eve et al., 2014;
West et al., 2010

GHG reductions from avoiding nitrogen fertilizer use

$$E_{CO_2e} = E1_{CO_2e} + E2_{CO2e}$$

$$E1_{CO_2e} = (F_{SN} \times EF_{direct} + F_{SN} \times EF_{indirect}) \times N_2O_{MW} \times GWP_{N_2O}$$

Application of fertilizer

denitrification/nitrification *volatilization*

$F_{SN} = avoided\ application\ of\ fertilizer\ [kg\ N\ ha^{-1}year^{-1}]$

$N_2O_{MW} = moleculare\ weight\ ratio\ [dimensionless]$

$E2_{CO2e} = F_{SN}\ x\ EF_{prod}$

Production of fertilizer

$EF_{prod} = GHG\ emissions\ for\ fertilizer\ production$

Tabacco and Comino, 2016;
IPCC, 2023;
IPCC, 2019.

Results: GOAL 1 (LCA study)

PRODUCTION VOLUMES-WEIGHTED AVERAGE RESULTS (5/23 companies)

1 ton of products (88% dry mass)

PROCESSES




Impact Category	Abbrev.	Unit of measure	Total	Agricultural processing	Transport field/facility	Drying and packaging	Distribution to customers
Climate change	**GWP**	kg CO_2 eq	**2,43E+02***	*4,97E+01*	1,13E+01	***1,15E+02***	*6,69E+01*
Ozone depletion	**ODP**	kg CFC11eq	6,31E-06	1,04E-06	1,71E-07	3,81E-06	1,28E-06
Ionising radiation	**IRP**	kBq U-235 eq	6,17E+00	7,83E-01	2,93E-01	4,14E+00	9,48E-01
Photochemical ozone formation	**POC**	kg NMVOC eq	1,97E+00	8,51E-01	9,84E-02	3,58E-01	6,66E-01
Particulate matter	**PMF**	Disease inc.	7,48E-06	9,00E-07	5,08E-07	1,00E-06	5,07E-06
Human toxicity, non-cancer	**HTP-nc**	CTUh	1,93E-06	7,89E-07	2,77E-07	3,22E-07	5,44E-07
Human toxicity, cancer	**HTP - c**	CTUh	7,43E-08	9,86E-09	1,33E-08	2,08E-08	3,02E-08
Acidification	**AP**	mol H+ eq	1,61E+00	5,42E-01	7,76E-02	2,24E-01	7,70E-01
Eutrophication, freshwater	**EP-fw**	kg P eq	1,78E-02	3,61E-03	2,49E-03	7,70E-03	4,05E-03
Eutrophication, marine	**EUP-m**	kg P eq	7,44E-01	4,58E-01	2,65E-02	6,59E-02	1,94E-01
Eutrophication, terrestrial	**EUP-t**	mol N eq	5,95E+00	2,84E+00	2,86E-01	7,12E-01	2,12E+00
Ecotoxicity, freshwater	**ET- f**	CTUe	1,52E+03	8,67E+02	5,65E+01	1,49E+02	4,50E+02
Land use	**LUP**	Pt	2,77E+03	1,89E+03	1,30E+02	8,80E+01	6,67E+02
Water use	**WDP**	m3 depriv.	2,14E+01	2,57E+00	1,07E+00	1,41E+01	3,76E+00
Resource use, fossils	**RU-f**	MJ	**3,50E+03**	6,82E+02	1,32E+02	***1,77E+03***	9,21E+02
Resource use, minerals and metals	**RU-m**	kg Sb eq	4,12E-04	8,07E-05	7,92E-05	1,07E-04	1,45E-04
Climate change - fossil	**GWP-f**	kg CO_2 eq	2,49E+02	5,64E+01	1,14E+01	1,14E+02	6,68E+01
Climate change - biogenic	**GWP-b**	kg CO_2 eq	-6,27E+00	-6,69E+00	1,21E-01	5,23E-01	2,56E-02
Climate change - land use change	**GWP-L**	kg CO_2 eq	8,97E-02	1,22E-02	1,96E-02	1,51E-02	4,28E-02

**Min*: 202 kg CO2 eq; *Max*: 361 kg CO_2 eq; *Dev std*: 50,6 kg CO_2 eq

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LIFE CYCLE ASSESSMENT DNV ISO 14040/44

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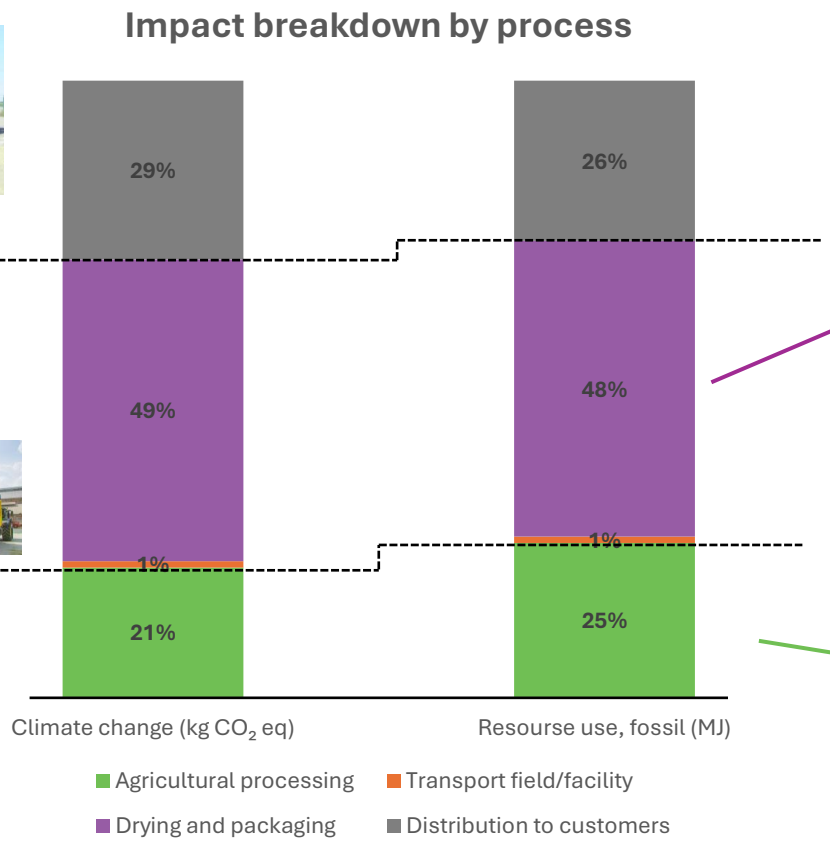
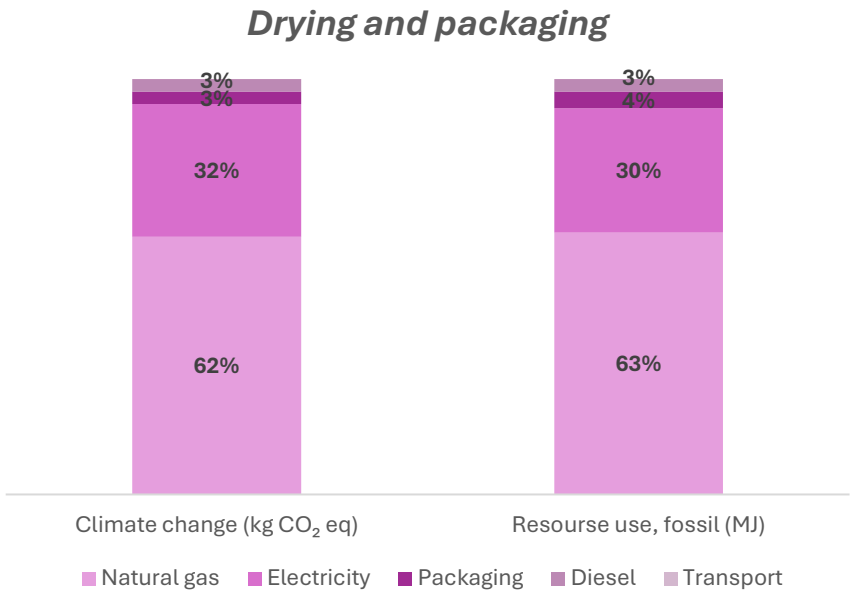
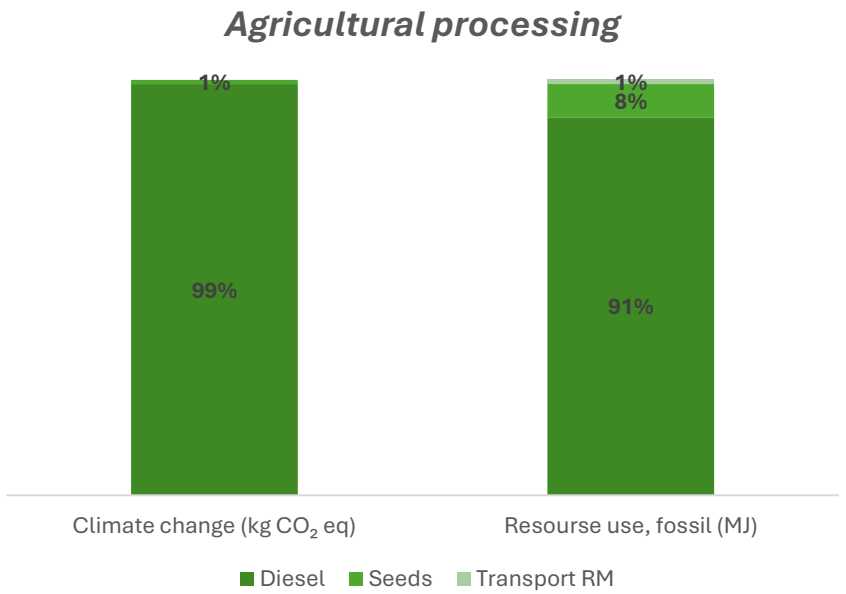
Results: GOAL 1 (LCA study)







Results: GOAL 2 (potential benefits)

UPTAKE IN ABOVEGROUND BIOMASS

Yield (av.):7,8 ± 1,3 tonSS/ha year

Uptake (av): 13,4 ± 2,2 tonCO_2/ha year

UPTAKE IN BELOWGROUND BIOMASS

Yield (av.):2,5 ± 0,4 tonSS/ha

Uptake (av): 4,3 ± 0,7 tonCO_2/ha

Uptake (av): 1,1 ± 0,2 tonCO_2/ha year*

GHG REDUCTIONS FROM AVOIDING NITROGEN FERTILIZER USE

Avoided app. fertilizer: 26 kgN/ha

Avoided emissions use of fert.: 0,12 tonCO_2e/ha

Avoided emissions use of fert.: 0,07 tonCO_2e/ha

GHG reductions total: ≈0,05 tonCO_2e/ha year*

*considering a lifespan of the alfalfa stand of 4 years

2,1 ± 0,3 tonCO_2eq/ha year

Results and discussions

- The **drying phase is the main hotspot** (≈45–50% of climate change and fossil energy use), with natural gas combustion responsible for most of the emissions. Therefore, the main improvement opportunities lie in **decarbonizing the drying process**, for example through:
  - higher-efficiency dryers;
  - biomass-fuelled systems to reduce fossil fuel demand;
  - waste heat recovery solutions;
  - increased use of renewable electricity (companies equipped with PV systems already show a 10–20% reduction in Scope 2 emissions).

- **Distribution and cultivation** also represent relevant hotspots due to **diesel combustion** in transportation and field operations, respectively.

- **Above-ground carbon uptake** is substantial and completely offset production related emissions, but it cannot be counted as carbon sequestration because of its short residence time (the absorbed carbon is released downstream along the value chain).

- **Below-ground** biomass may contribute to temporary **soil carbon storage**, particularly in crop rotations, and can partially offset production-related emissions. However, field-level measurements are required to determine how much of the root biomass is effectively converted into long-term soil organic carbon.

- Alfalfa also fixes **atmospheric nitrogen** biologically and therefore avoids the use of synthetic fertilizers. According to our estimates, this results in a positive but relatively small contribution in terms of climate change mitigation.

This study is intended as a starting point for Italian forage producers. It will be extended to a larger number of companies and supported by improved primary data collection in future iterations.