FACCE-MACSUR

D-L2.4 Modelling the impact of climate change on livestock productivity at the farm-scale: An inventory of LiveM outcomes

v1.0.1

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Abstract/Executive summary

The report presented here provides an inventory of reports and conference papers produced by the partners of the livestock and grassland modelling theme (LiveM) of the Modelling European Agriculture with Climate Change for Food Security (MACSUR) knowledge hub. The findings presented illustrate the diverse nature of the multi-disciplinary LiveM research community, and provide a reference source for those seeking to identify and pull out farm-level modelling outputs from the work of MACSUR and its partners. The survey of farm-scale outputs from LiveM revealed the interdependent, dual role of a knowledge hub: to increase the capacity of modelling to meet stakeholder and societal needs under climate change, and to apply that increased capacity to provide new understanding and solutions at the policy and (the focus here) farm scale. While capacity building work across disciplines is time-consuming, difficult, and to a large extent invisible to stakeholders, such work is vital to ensuring that subsequent scientific outcomes reflect best practice, and integrated expertise. Long term, sustained funding of network-based capacity building activities is highlighted as essential to ensuring that the farm-scale modelling work highlighted here can continue to build on ongoing improvements in model quality, flexibility and stakeholder relevance.

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Introduction

The Modelling European Agriculture with Climate Change for Food Security (MACSUR) knowledge hub aims to improve the capacity of agricultural models to predict the impacts of climate change on farming and (consequently) on food security, and to evaluate both measures aimed at mitigating agricultural greenhouse gas emissions, and strategies for adaptation to climate change. Improving the usefulness and quality of models for use by stakeholders at policy and farm scale is central to the aims of the project. In this report, outcomes from the livestock and grassland modelling theme of MACSUR (LiveM) are inventoried and analysed to explore the messages they contain for farm-level stakeholders (e.g. farmers, farm-managers, farm advisors). The inventory presented draws on both work produced within the project, and research undertaken by partners and presented at MACSUR conferences. This scope reflects the role of a knowledge hub in drawing together and synthesizing disparate research activities across the academic community, improving the capacity of partners to undertaken such activities, and to do so within a network that facilitates collaboration and the spread of best practice.

Method

In order to compile an inventory of the farm-scale relevant outputs of LiveM, the MACSUR project website was used to identify and categorise relevant reports and papers (http://macsur.eu/index.php/output/products-and-publications). The following products were categorised:

- Reports from first and second phase of MACSUR
- Short papers/abstracts presented at conferences in Sassari 1-3 March 2013, in Bilbao 14-16 October 2014 and Potsdam 15-16 June 2016 (extended abstracts from the Bilbao and Potsdam conferences were published in special issues of Advances in Animal Biosciences: vol 6 issue 1, and vol 7 issue 3)
- Published position papers
- Other published full papers acknowledging MACSUR

Authors of reports and papers were contacted and asked to fill in an electronic questionnaire (Table 1) designed to draw out the farm-relevant outcomes of their work. The questionnaire identified reports/papers with outcomes relevant at the farm scale, asked about the themes, animals/systems, geographical focus and type of impacts covered by the report/paper, further reports / papers in which the presented ideas had been developed since the report/paper was published, and invited authors to describe their farm-relevant findings.

Table 1 Questionnaire to categorise products for LiveM in Macsur, question (Q) 1 to 8.

Q1	Report title, deliverable
Q2	Does the report contain findings
	- Specifically relating to farm-scale
	- Not specific to farm-scale but with potential interest for farm-scale
	- No findings with any farm scale connection or interest
Q3	Please give a summary of each farm-relevant finding (max 50 words for each finding). You can add more rows if required.
	- Finding 1....., finding 2
Q4	Are there any publications related to the information in the report? (please provide reference details so we can review them)
Q5	Which themes best represent the focus of each of your farm-relevant findings?
	- Mitigation; Adaptation; Modelling; Animal health/disease; Grassland; Milk production of cattle; Milk production of other animals; Meat production; Enteric methane production;

	Review/position paper; Policy ; Farm management; Qualitative aspects of farming; Other (please name):
Q6	Which animals / systems do your findings focus on?
	- Grassland; Feed crops; Ruminants in general; Dairy cattle; Meat cattle; Bovine in general; Goat; Sheep; Poultry; Pigs; Other (please name):
Q7	What is the geographical focus of your findings?
	- NW Europe; NE Europe; SW Europe; SE Europe; Africa; America; Asia; Oceania; Not region specific; Other (please name):
Q8	Do your findings provide information related to:
	- CO2 emissions; CH4 emissions; N2O emissions; Energy use; Nutrients; Water use; Policy making; Land use change; Disease management; Other (please name):

Results

On the website 17 reports (Table 2), 40 short papers (Table 3), 19 full papers (Table 4) and 3 position papers (Table 5) related to livestock production were found.

Categorisation of reports and papers
The reports and papers were categorised using the answers to Q2 (farm scale or not), Q6 (animal type/system), Q7 geographical focus and Q8 type of impact.

Reports (Table 6a)
In five reports farm scale findings were identified. In eight reports authors identified only 'potentially' farm-relevant findings, and in four reports no farm-scale outcomes were identified.
In the reports topics were:
- Grassland (10 reports)
- Disease management of ruminants, with an emphasis on dairy cattle, and pigs (four reports)
- Climate change in general (one report)
- Modelling in general (one report)
- Ruminant GHG emissions (one report)

The geographical focus was on Europe (15 reports) or not specific (two reports).

Short papers (Table 6b)
In 18 short papers farm-relevant findings were identified (including one both direct and potentially farm scale), in 13 short papers authors identified only 'potentially farm-relevant' findings, and nine short papers no farm-scale findings were identified.
In the short papers frequent topics were:
- Grassland (eight short papers)
- Disease management and/or heat stress of ruminants, with an emphasis on dairy cattle, and pigs (12 short papers)

The geographical focus was in general on Europe (28 short papers), not specific (11) or South America (one).

Full papers (Table 6c)
In seven full papers farm scale findings were included, in four full papers only 'potentially farm-relevant' findings were identified, and nine full papers identified no farm scale findings.
In the papers frequent topics were:
- Grassland (seven papers)
- Heat stress of dairy cattle (four papers)

The geographical focus was on Europe (15 papers) or not specific (five).

Position papers (Table 6d)
In the position papers, no direct farm scale findings were identified. Instead, the papers were aimed at setting the European research agenda for the modelling of ruminant systems, grasslands, and animal health and pathogens, under climate change. Their purpose was therefore to support the development of modelling capacity to optimise the usefulness of modelling to farm and policy level stakeholders facing the challenges of climate change, rather than to present findings for stakeholders. The geographical focus of the position papers was pan-European.

Farm scale results
Farm-scale results described by authors (Table 1, Q3) were analysed and divided into five groups:
1) General, mitigation and adaptation (Table 7)
2) Animal health (Table 8)
3) Heat stress of animals (Table 9)
4) Farm modelling (Table 10)
5) Indirect farm scale results (Table 11)

The majority of farm scale results were found in papers and reports on animal health and disease (including heat stress) in 17 papers and reports. The farm scale results on grasslands are limited to four papers and reports.

Table 2 Categorised reports (R) from MACSUR, title and authors, sorted alphabetically by surname of first author.

nr	TITLE	AUTHOR
R1	Identification of datasets on climate change in relation to livestock productivity (production and fitness traits) and livestock infectious disease	Dave Bartley
R2	Datasets classification and criteria for data requirements	Gianni Bellocchi, Shaoxiu Ma, Martin Köchy, Katharina Braunmiller
R3	Identified grassland-livestock production systems and related models	Gianni Bellocchi, Shaoxiu Ma, Martin Köchy, Katharina Braunmiller
R4	Model intercomparison	Gianni Bellocchi, Renáta Sándor
R5	Protocol for model evaluation	Gianni Bellocchi, Mike Rivington, Marco Acutis
R6	Results of uncalibrated grassland model runs	Gianni Bellocchi, Shaoxiu Ma
R7	Grassland datasets	Katharina Braunmiller, Martin Köchy
R8	Synergies between mitigation and adaptation to Climate Change in grassland-based farming systems	Agustin Del Prado, Agnes van den Pol-van Dasselaar, D. Chadwick, Tom Misselbrook, Daniel Sandars, Eric Audsley, M. R. Mosquera-Losada
R9	Inventory of farm-scale models within LiveM	Nicholas Hutchings, Richard Kipling
R10	Appropriate meta-data for modellers	Richard Kipling, Kairsty Topp, Axel Don
R11	The availability of carbon sequestration data in Europe	Richard Kipling, Kairsty Topp, Axel Don
R12	Maps of grasslands in Europe	Martin Köchy
R13	National and transnational dairy cows biometeorological datasets linked to productive, reproductive and health performances data	Nicola Lacetera
R14	Report on relationships between THI and dairy cow performance	Nicole Lacetera, Andrea Vitali, Umberto Bernabucci, Alessandro Nardone
R15	Report on the analysis of interannual and seasonal variations in productive, reproductive and health data	Nicola Lacetera, Andrea Vitali, Umberto Bernabucci, Alessandro Nardone
R16	Uncertainties in climate change prediction and modelling	Susanne Rolinski, Eli Sætnan
R17	Report on Stakeholder Engagement Methodologies	Giovanna Seddaiu, Maria Laura Ruiu, Richard P Kipling

Table 3 Categorised short papers (S) from MACSUR, title and authors, sorted alphabetically by surname of first author.

nr	TITLE	AUTHOR
S1	Effects of roughage characteristics on enteric methane emission in dairy cows.	Bannink, A.; and Dijkstra, J.
S2	Endemic sheep and cattle diseases and greenhouse gas emissions.	Bartley, D.; Skuce, P.; Zadoks, R.; and MacLeod, M.
S3	C and N models Intercomparison – benchmark and ensemble model estimates for grassland production.	Sándor, R.; Ehrhardt, F.; Basso, B.; Bellocchi, G.; Bhatia, A.; Brilli, L.; Migliorati, M.; Doltra, J.; Dorich, C.; Doro, L.; Fitton, N.; Giacomini, S.; Grace, P.; Grant, B.; Harrison, M.; Jones, S.; Kirschbaum, M.; Klumpp, K.; Laville, P.; Léonard, J.; L
S4	Modelling the impacts of seasonal drought on herbage growth under climate change.	Calanca, P.
S5	Assessing dairy farm sustainability using whole-farm modelling and life cycle analysis.	Mas, K.; Pardo, G.; Galán, E.; and del Prado, A.
S6	Lifetime nitrogen use efficiency of dairy cattle: model description and sensitivity analysis	A. Foskolos (a1) and J. M. Moorby
S7	Heat stress effects in milk yield and milk traits at farm scale.	Galán, E.; Sanchis, E.; Estellés, F.; Calvet, S.; and del Prado, A.
S8	An index-based production costs system to evaluate costs of adaptation and mitigation in dairy and cattle farming	Heinschink, K.; Sinabell, F.; and Tribl, C.
S9	Integrated modelling to assess optimisation potentials for cattle housing climate.	Hempel, S.; Janke, D.; König, M.; Menz, C.; Englisch, A.; Pinto, S.; Sibony, V.; Halachmi, I.; Rong, L.; Zong, C.; Zhang, G.; Sanchis, E.; Estelle, F.; Calvet, S.; Galan, E.; del Prado, A.; Ammon, C.; Amon, B.; and Amon, T.
S10	Process-based simulation of growth and overwintering of grassland using the BASGRA model.	Höglind, M.; Van Oijen, M.; Cameron, D.; and Persson, T.
S11	Stakeholder engagement and the perceptions of researchers: how agricultural modellers view challenges to communication.	Kipling, R.; and Özkan Gülzari, Ş.
S12	Modelling heat stress on livestock: how can we reach long-term and global coverage.	Leclère, D.; and Havlík, P.
S13	Simulation of enteric methane emissions from individual beef cattle in tropical pastures of improving quality: a case study with the model RUMINANT.	Mendes, L.; Herrero, M.; Havlík, P.; Mosnier, A.; Balieiro, S.; Moreira, R.; and Obersteiner, M.
S14	Heat stress impacts on cows in a case study landscape measured by an integrated modelling framework.	Schönhart, M.
S15	Exploring grass-based beef production under climate change by integration of grass and cattle growth models.	van der Linden, A.; van de Ven, G.; Oosting, S.; van Ittersum, M.; and de Boer, I.
S16	Modelling responses of forages to climate change with a focus on nutritive value.	Virkajärvi, P.; Korhonen, P.; Bellocchi, G.; Curnel, Y.; Wu, L.; Jégo, G.; Persson, T.; Höglind, M.; Van Oijen, M.; Gustavsson, A.; and Kipling, R. Advances in Animal Biosciences, 7: 227–228. 2016. MACSUR or FACCE acknowledged.
S17	Effect of season, month and temperature humidity index on the occurrence of clinical mastitis in dairy heifers	Vitali, A.; Bernabucci, U.; Nardone, A.; and Lacetera, N.
S18	Vul'Clim – Climate change vulnerability studies in the region Auvergne (France)	Gianni Bellocchi, Raphaël Martin, Anastasiya Shtiliyanova, Haythem Ben Touhami, Pascal Carrère
S19	Farm level approach to manage grass yield variation in changing climate in Jokioinen and St. Petersburg	Pellervo Kässi, Olli Niskanen, Hannu Känkänen

nr	TITLE	AUTHOR
S20	Relationships between temperature humidity index, mortality, milk yield and composition in Italian dairy cows	Nicola Lacetera, Andrea Vitali, Umberto Bernabucci, Alessandro Nardone
S21	Effect of Increased Somatic Cell Count and Replacement Rate on Greenhouse Gas Emissions in Norwegian Dairy Herds	Șeyda Özkan, Helge Bonesmo, Olav Østerås, Odd Magne Harstad
S22	Pasture harvest, carbon sequestration and feeding potentials under different grazing intensities	S. Rolinski (a1), I. Weindl (a1) (a2), J. Heinke (a1) (a3), B. L. Bodirsky (a1), A. Biewald (a1) and H. Lotze-Campen
S23	Further effects of forage on greenhouse gases estimated byDairyCant for dairy farms	G. Salcedo1†, A. Villar2, J. Doltra2, B. Fernández2, M. Mora2, J. Busque2, M. Domínguez2 and R. Moros2
S24	A systems-life cycle assessment approach to modelling the impact of improvements in cattle health on greenhouse gas emissions	A. Williams1†, J. Chatterton1, G. Hateley2, A. Curwen3 and J. Elliott4
S25	Research and innovation for a competitive and sustainable animal production sector in a climate changing Europe: linking up MACSUR with Animal Task Force	M. C. T. Scholten
S26	Making a decision-support system for dairy farmers usable throughout Europe: the challenge of feed evaluation	L. Baldinger, J. Vaillant, W. Zollitsch, M. Rinne
S27	An integrated simulation and optimization model of sheep farms as a tool to explore technical and environmental objectives	D. Villalba, B. Díez-Unquera, A. Carrascal, A. Bernués, R. Ruiz
S28	The need for a quantitative assessment of animal welfare trade-offs in climate change mitigation scenarios	P. Llonch, A. B. Lawrence, M. J. Haskell, I. Blanco-Penedo, S. P. Turner
S29	Rumination time, milk yield, milking frequency of grazing dairy cows milked by a mobile automatic system during mild heat stress	F. Lessire, J. L. Hornick, J. Minet, I. Dufrasne
S30	Effects of heat waves on mortality of dairy cows	A. Vitali, A. Felici, S. Esposito, U. Bernabucci, L. Bertocchi, C. Maresca, A. Nardone, N. Lacetera
S31	Direct climate change impacts on cattle indicated by THI models	M. Schönhart, I. Nadeem
S32	Eco-DREAMS-S: modelling the impact of climate change on milk performance in organic dairy farms	A. Ruete, A. Velarde, I. Blanco-Penedo
S33	Impact of animal health on greenhouse gas emissions	Ş. Özkan, B. V. Ahmadi, H. Bonesmo, O. Østerås, A. Stott, O. M. Harstad
S34	DairyCant: a model for the reduction of dairy farm greenhouse gas emissions	G. Salcedo
S35	Modelling livestock parasite risk under climate change	N. J. Fox, R. S. Davidson, G. Marion, M. R. Hutchings
S36	A holistic, dynamic model to quantify and mitigate the environmental impacts of cattle farming	J.-M. Katajajuuri, H. Pulkkinen, S. Hietala, K. Järvenranta, P. Virkajärvi, J. I. Nousiainen, A. Huuskonen
S37	Modelling the impact of environmental changes on grassland systems with SPACSYS	L. Wu, A. P. Whitmore, G. Bellocchi
S38	Modelling the impact on greenhouse gas emissions of using underutilized feed resources in dairy goat systems	G. Pardo, D. Yañez-Ruiz, I. Martin-Garcia, A. Arco, R. Moral, A. del Prado
S39	Uncertainty in simulating biomass yield and carbon–water fluxes from grasslands under climate change	R. Sándor, S. Ma, M. Acutis, Z. Barcza, H. Ben Touhami, L. Doro, D. Hidy, M. Köchy, E. Lellei-Kovács, J. Minet, A. Perego,S. Rolinski, F. Ruget, G. Seddaiu, L. Wu, G. Bellocchi
S40	Developing skills: how to train adaptive modelers	D. Wallach

Table 4 Categorised full papers (TF) from MACSUR, title and authors, sorted alphabetically by surname of first author.

nr	TITLE	AUTHOR
TF1	An open platform to assess vulnerabilities to climate change: An application to agricultural systems.	Eza, U.; Shtiliyanova, A.; Borras, D.; Bellocchi, G.; Carrère, P.; and Martin, R.
TF2	Multi-model simulation of soil temperature, soil water content and biomass in Euro-Mediterranean grasslands: Uncertainties and ensemble performance.	Sándor, R.; Barcza, Z.; Acutis, M.; Doro, L.; Hidy, D.; Köchy, M.; Minet, J.; Lellei-Kovács, E.; Ma, S.; Perego, A.; Rolinski, S.; Ruget, F.; Sanna, M.; Seddaiu, G.; Wu, L.; and Bellocchi, G.
TF3	Deliberative processes for comprehensive evaluation of agroecological models. A review.	Bellocchi, G.; Rivington, M.; Matthews, K.; and Acutis, M.
TF4	Modelling of grassland fluxes in Europe: evaluation of two biogeochemical models.	Sándor, R.; Barcza, Z.; Hidy, D.; Lellei-Kovács, E.; Ma, S.; and Bellocchi, G. Agriculture, Ecosystems and Environment, 215: 1–19. 2016. MACSUR or FACCE acknowledged.
TF5	Multi-model simulation of soil temperature, soil water content and biomass in Euro-Mediterranean grasslands: Uncertainties and ensemble performance.	Sándor, R.; Barcza, Z.; Acutis, M.; Doro, L.; Hidy, D.; Köchy, M.; Minet, J.; Lellei-Kovács, E.; Ma, S.; Perego, A.; Rolinski, S.; Ruget, F.; Sanna, M.; Seddaiu, G.; Wu, L.; and Bellocchi, G. European Journal of Agronomy, (in press). 2016.
TF6	Bayesian calibration of the Pasture Simulation model (PaSim) to simulate European grasslands under water stress.	Ben Touhami, H.; and Bellocchi, G.
TF7	The effects of heat stress in Italian Holstein dairy cattle.	Bernabucci, U.; Biffani, S.; Buggiotti, L.; Vitali, A.; Lacetera, N.; and Nardone, A.
TF8	Seasonal variations in the composition of Holstein cow's milk and temperature-humidity index relationship.	Bertocchi, L.; Vitali, A.; Lacetera, N.; Nardone, A.; Varisco, G.; and Bernabucci, U.
TF9	Land use dynamics and the environment.	Camacho, C.; and Pérez-Barahona, A.
TF10	Modelling heat stress under different environmental conditions.	Carabano, M.; Logar, B.; Bormann, J.; Minet, J.; Vanrobays, M.; Diaz, C.; Tychon, B.; Gengler, N.; and Hammami, H.
TF11	Extending and improving regionalized winter wheat and silage maize yield regression models for Germany: Enhancing the predictive skill by panel definition through cluster analysis.	Conradt, T.; Gornott, C.; and Wechsung, F.
TF12	Winners and losers from climate change in agriculture: Insights from a case study in the Mediterranean basin	Dono, G.; Cortignani, R.; Dell'Unto, D.; Deligios, P.; Doro, L.; Lacetera, N.; Mula, L.; Pasqui, M.; Quaresima, S.; Vitali, A.; and Roggero, P
TF13	Perceiving to learn or learning to perceive? Understanding farmers' perceptions and adaptation to climate uncertainties.	Nguyen, T.; Seddaiu, G.; Virdis, S.; Tidore, C.; Pasqui, M.; and Roggero, P.
TF14	Evaluation of the LINGRA timothy model under Nordic conditions.	Persson, T.; Höglind, M.; Gustavsson, A.; Halling, M.; Jauhiainen, L.; Niemeläinen, O.; Thorvaldsson, G.; and Virkajärvi, P.
TF15	Impact of soil type extrapolation on timothy grass yield under baseline and future climate conditions in southeastern Norway.	Persson, T.; Kværnø, S.; and Höglind, M.
TF16	Scenario analysis of alternative management options on the forage production and greenhouse gas emissions in Mediterranean grasslands.	Pulina, A.; Bellocchi, G.; Seddaiu, G.; and Roggero, P. P.
TF17	Irish farms under climate change – is there a regional variation on farm responses?.	Shrestha, S.; Abdalla, M.; Hennessy, T.; Forristal, D.; and Jones, M.
TF18	The effect of heat waves on dairy cow mortality.	Vitali, A.; Felici, A.; Esposito, S.; Bernabucci, U.; Bertocchi, L.; Maresca, C.; Nardone, A.; and Lacetera, N.
TF19	Livestock in a changing climate: production system transitions as an adaptation strategy for agriculture.	Weindl, I.; Lotze-Campen, H.; Popp, A.; Müller, C.; Havlík, P.; Herrero, M.; Schmitz, C.; and Rolinski, S.
TF20	Process-based simulation of growth and overwintering of grassland using the BASGRA model	Mats Höglind, Marcel Van Oijen, David Cameron, Tomas Persson

Table 5 Categorised full position papers (PF) from project MACSUR, title and authors, sorted alphabetically by surname of first author.

nr	TITLE	AUTHOR
PF1	Key challenges and priorities for modelling European grasslands under climate change.	Kipling, R.; Virkajärvi, P.; Breitsameter, L.; Curnel, Y.; De Swaef, T.; Gustavsson, A.; Hennart, S.; Höglind, M.; Järvenranta, K.; Minet, J.; Nendel, C.; Persson, T.; Picon-Cochard, C.; Rolinski, S.; Sandars, D.; Scollan, N.; Sebek, L.; Seddaiu, G.; Topp, C.; Twardy, S.; Van Middelkoop, J.; Wu, L.; and Bellocchi, G.
PF2	Modelling European ruminant production systems: Facing the challenges of climate change.	Kipling, R.; Bannink, A.; Bellocchi, G.; Dalgaard, T.; Fox, N.; Hutchings, N.; Kjeldsen, C.; Lacetera, N.; Sinabell, F.; Topp, C.; van Oijen, M.; Virkajärvi, P.; and Scollan, N.
PF3	Challenges and priorities for modelling livestock health and pathogens in the context of climate change.	Özkan, Ş.; Vitali, A.; Lacetera, N.; Amon, B.; Bannink, A.; Bartley, D.; Blanco-Penedo, I.; de Haas, Y.; Dufrasne, I.; Elliott, J.; Eory, V.; Fox, N.; Garnsworthy, P.; Gengler, N.; Hammami, H.; Kyriazakis, I.; Leclère, D.; Lessire, F.; Macleod, M.; Robinson, T.; Ruete, A.; Sandars, D.; Shrestha, S.; Stott, A.; Twardy, S.; Vanrobays, M.; Ahmadi, B.; Weindl, I.; Wheelhouse, N.; Williams, A.; Williams, H.; Wilson, A.; Østergaard, S.; and Kipling, R

Table 6a Categorised Reports (R) from MACSUR, answers to questions 2, 6, 7 and 8: general features

nr	Q2 Farm scale	Q2 Potentially farm scale	Q2 no farm scale	Q6 animal system	Q7 geographical focus	Q8 info type
R1		X	x	Ruminants in general	NW Europe	Disease management
R2		X		Grassland	NW+SW Europe, Israel	CO_2 emissions,Water use
R3		X		Grassland	NW+SW Europe, Israel	CO_2 emissions,Water use
R4		X		Grassland	NW+SW Europe, Israel	Modelling
R5		X		Virtually any agricultural system	Not specific	Modelling
R6		X		Grassland	NW+SW Europe, Israel	CO_2 emissions,Water use
R7			x	Grassland	NW+SW Europe, Israel	Data collection
R8	x			Grassland, ruminants in general	Europe	Total GHG emission, trade-offs to other losses
R9		X		Ruminants in general, pigs	Europe	Total GHG emission, farm management
R10			x	Grassland	Europe	Meta data requirements for online resource
R11			x	Grassland	Europe	Capacity building for modelling
R12			x	Grassland	Europe	Land use change, Scaling up, generalisation, data sources
R13	x			Dairy cattle, pigs	NE+SW Europe	Disease management
R14	x			Dairy cattle, pigs	NE+SW Europe	Disease management
R15	x			Dairy cattle, pigs	NE+SW Europe	Disease management
R16		X		Grassland	Not specific	GHG
R17	x	X		Climate change in general	Not specific	Knowledge exchange

Table 6b Categorised short papers (S) from MACSUR, answers to questions 2, 6, 7 and 8: general features

nr	Q2 Farm scale	Q2 Potentially farm scale	Q2 no farm scale	Q6 animal system	Q7 geographical focus	Q8 info type
S1	x			Dairy cattle, grassland	NW Europe, Europe	CH_4 emissions
S2	x			Dairy cattle, meat cattle, sheep	NW Europe, Europe	Disease management, GHG emission
S3		X	x	Grassland	Europe	Grassland model intercomparison
S4		X	x	Grassland	Europe	Grassland response to water deficiency
S5	x			Dairy cattle	SW Europe	CO_2/CH_4/N_2O emissions, dairy farms
S6		X		Dairy cattle	Not specific	Consequence of replacement of dairy cows
S7	x			Dairy cattle	SW Europe, SE Europe	Heat stress of dairy cattle
S8	x			Dairy cattle, beef cattle	(Central) Europe	Economics
S9		X		Cattle (indoors)	Not specific	Disease management, animal welfare, heat stress
S11		X		Stakeholders+researchers	Europe	Interaction stakeholders-researchers
S12			x	Mammals in general	Not specific	Heat stress
S13	x			Beef cattle	South America	Model calculations
S14	x	X		Dairy cattle	Central Europe	Disease management, heat stress
S15	x			Beef cattle	SW Europe	Optimization of animal density in future climate scenarios
S16			x	Grassland	Europe	Grassland, adaptation
S17	x			Dairy cattle	Europe	Disease management, heat stress
S18			x	Grassland	SW Europe	Regional scale grassland
S19	x			Grassland	Not specific	Modelling necessary storage capacity for roughage
S20	x			Dairy cattle	SW europe	Disease management, heat stress
S21	x			Dairy cattle	NW Europe	Disease management, heat stress
S22		X		Dairy cattle	World	Grassland production, carbon sequestration
S23	x			Dairy cattle	SW Europe	GHG emissions on farm
S24		X		Dairy cattle, beef cattle	Not specific	GHG emissions on farm
S25			x	Animal production in general	Europe	Linking research and stakeholders
S26		X		Dairy cattle, low inut, organic	NW Europe	Feeding value
S27	x			Sheep	SW Europe	GHG emission sheep farm
S28		X		Mammals in general	Not specific	GHG emission and animal welfare
S29	x			Dairy cattle	NW Europe	Heat stress and milk production
S30	x			Dairy cattle	SW Europe	Heat stress and mortality
S31	x			Dairy cattle, suckler cows	Europe	Modelling Heat stress and milk production
S32	x			Dairy cattle	SW Europe	Modelling Heat stress and milk production
S33				Dairy cattle	NW Europe	Modelling disease
S34		X		Dairy cattle	SW Europe	Modelling dairy farm
S35		X		Ruminants	Not specific	Modelling parasite pressure
S36		X		Beef cattle	Not specific	Modelling farm, incl LCA

nr	Q2 Farm scale	Q2 Potentially farm scale	Q2 no farm scale	Q6 animal system	Q7 geographical focus	Q8 info type
S37			x	Grassland	Not specific	Grassland modelling
S38		X		Goat, dairy	SW Europe	Modelling goat diets in LCA
S39			x	Grassland	Europe	Modelling grassland, calibration
S40			x	Not specific	Not specific	Modelling as activity for researchers

Table 6c Categorised full papers (TF) from MACSUR, answers to questions 2, 6, 7 and 8: general features

nr	Q2 Farm scale	Q2 Potentially farm scale	Q2 no farm scale	Q6 animal system	Q7 geographical focus	Q8 info type
TF1		X		Not specific	Not specific	Farm system modelling
TF2			x	Grassland	SW Europe	Grassland modelling
TF3			x	Not specific	Not specific	Farm system modelling
TF4			x	Grassland	Europe	Grassland modelling
TF5			x	Grassland	Europe	Grassland modelling
TF6			x	Grassland	Europe	Grassland modelling
TF7	x			Dairy cattle	SW Europe	Modelling heat stress
TF8	x			Dairy cattle	SW Europe	Modelling heat stress
TF9			x	Not specific	Not specific	Farm system modelling
TF10	x			Dairy cattle	NW+SW Europe	Modelling heat stress
TF11			x	Not specific	NW Europe	Crop modelling
TF12	x			Not specific	SW Europe	Knowledge exchange
TF13		X		Not specific	Not specific	Knowledge exchange
TF14			x	Grassland	NW Europe	Grassland modelling
TF15	x			Grassland	NW Europe	Grassland modelling
TF16		X		Not specific	SW Europe	System modelling
TF17	x			Ruminants	NW Europe	Farm modelling
TF18	x			Dairy cattle	SW Europe	Modelling heat stress
TF19			x	Not specific	Not specific	System modelling, economy
TF20		X		Grassland	NW Europe	Grassland

Table 6d Categorised position papers (PF) from MACSUR, answers to questions 2, 6, 7 and 8: general features

nr	Q2 Farm scale	Q2 Potential farm scale	Q2 no farm scale	Q6 animal system	Q7 geographical focus	Q8 info type
PF1			x	Grassland	Not specific	Modelling
PF2			x	Ruminant	Not specific	Modelling
PF3			x	Ruminant	Not specific	Modelling

Table 7 Farm scale results in reports and papers from MACSUR: general, mitigation and adaptation

nr	Theme	Q3 summary farm relevant
R16	General	Research of climate change impacts is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. The confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation).
R17	General, knowl exch	It is important to create new spaces for dialogue between farmers, researchers and policy makers in order to promote the generation of “hybrid knowledge” (Nguyen et al. 2013) for the emergence of more sustainable and longer-lasting strategies to adapt to CC. This would require the promotion of open knowledge generation platforms where multiple stakeholders are encouraged to participate and make their views heard. These approaches are designed in order to overcome the misalignment between scientists' suggestions and policy implementation.
TF13	General, knowl exch	Paper about knowledge exchange
R8	General, mitig/adapt in grassland based systems	Inventory if mitigation and adaptation measures e.g. on farm scale can contradict or enhance each other.
S1	Mitigation on dairy farms	Higher digestibility of grass and more silage maize in ration decreases enteric methane emission by dairy cows.
S13	Mitigation on dairy farms	Improving pasture management and small supplementation with corn silage reduce methane emission.
S5	Mitigation on dairy farms	For the C footprint, there is a large contribution of embedded emissions from purchased feed. CH4 origins from rumen, manure management, N_2O origins from on-farm soils. N losses come from Ammonia emissions, NO_3- leaching. More relations between GHG and N losses exist. Trade-offs between sustainability parameters exist.
S23	Mitigation on dairy farms	The highest values of CO_2-eq/kg ECM were observed in pasture-based systems. The cultivation of maize has an interesting potential for mitigating CH_4/kg ECM. From an environmental perspective, the planting of winter forage crops does not improve CO_2-eq.
S28	Mitigation	Animal welfare can be impaired by some GHG mitigation strategies but at the same time improved welfare can help to promote both animal efficiency and GHG emissions mitigation.
S15	Adaptation	The integrated models showed that there is scope to intensify grass-based beef production and mitigate the relative yield gap (41%) under the current climate from a bio-physical perspective.
S19	Adaptation	Farms can prepare for exceptional years by adjusting cultivated grass area and having extra storing capacity available. A model was built to analyse these adjusting possibilities.
S22	Adaptation	Assuming best practices for extensive managed grasslands under grazing could yield globally more than enough grass harvest for maintaining the existing dairy cattle. Although local restrictions were not considered for this first assessment, this could easily be incorporated.
TF12	Adaptation	Climate change will generate winners and losers in the Mediterranean agriculture. • Spring drought and high summer temperature are the key climatic drivers. • Intensive dairy cattle and rainfed dairy sheep systems will be the most affected. • Farm-scale adaptive responses will not be sufficient to mitigate the negative impact.
TF15	Adaptation	In the paper is an estimation of grass growth under climate change in Norway as dependent on soil type extrapolation. The simulated regional seasonal timothy yields were 5-13% lower on average and had higher inter-annual variability for the least detailed soil extrapolation. The simulated yield differed largely between climate projections.

Table 8 Farm scale results in reports and papers from MACSUR: Animal health

nr	Theme	Q3 summary farm relevant
S21	Health & mitigation	In this study, the impact of elevated SCC (200,000 cells/ml and above) and replacement rate on farm GHG emissions was evaluated. Preliminary results indicate an increasing trend in emissions (per kg milk and meat) as the SCC increases. Results suggest that animal health should be considered as an indirect mitigation strategy; however, further studies are required to enable comparisons of different farming systems.
S33	Health & mitigation	Results showed that the healthy cows, for any level of milk price, achieved higher Expected net present values (ENPVs) than the diseased cows . The GHG emissions produced per kg of milk increased in the diseased scenarios relative to the healthy scenario. This means keeping cows healthy is a potential for mitigation in herds with subclinical mastitis.
S2	Health & adaptation	'Top 3' of diseases to consider for potential eradication and/or government policy intervention: Neosporosis (beef cattle; major cause of abortion), IBR (dairy cattle; significant impact on milk production; eradication feasible) and PGE (sheep; impact on growth and feed conversion rates (FCRs)). Abatement possible, and likely to be economically viable and practically feasible for IBR and PGE. For Neosporosis: insufficient data available to substantiate abatement potential and feasibility of its control.
S17	Health & adaptation	Highest risk of clinical mastitis exists in July. When THI values > 79 there is a higher risk of clinical mastitis development for primaparous heifers
TF8	Health & adaptation	Milk characteristics data referred to somatic cell count (SCC), total bacterial count (TBC), fat percentage (FA%) and protein percentage (PR%). The summer season emerged as the most critical season. Of the summer months, July presented the most critical conditions for TBC, FA% and PR%, and August presented higher values of SCC. The analysis demonstrated a positive correlation between THI and SCC and TBC, and indicated a significant change in the slope at 57.3 and 72.8 maximum THI, respectively. The model demonstrated a negative correlation between THI and FA% and PR% and provided breakpoints in the pattern at 50.2 and 65.2 maximum THI, respectively. The results of this study indicate the presence of critical climatic thresholds for bulk tank milk composition in dairy cows. Such indications could facilitate the adoption of heat management strategies, which may ensure the health and production of dairy cows and limit related economic losses.

Table 9 Farm scale results in reports and papers from project MACSUR: Animal heat stress

nr	Theme	Q3 summary farm relevant
R14	Heat stress	- Heat stress affect negatively milk production traits that start to decline for values of THI observed 4 days before the test day and ranging between 73-76, 72-73 and 71-72 THI units for milk, protein and fat yield, respectively. Younger cows were less sensitive to heat stress than multiparous cows. - Nonreturn rate at 56 days after first insemination of dairy cows was significantly affected by THI, by 4 days before and 5 days after the insemination. Critical thresholds of THI above which reproduction efficiency decline were detected and they ranged between 72 and 75 units of THI. - Dairy cows mortality was greater during heat waves compared with normal summer days. The risk of mortality during summer heat waves was higher in older cows compared to younger ones. Moreover, the risk of death was higher during longer heat waves and for those occurred in early summer months. - The lower risk for the occurrence of mastitis in dairy heifers was recorded for thermal comfort zone (THI<70) and for mild heat stress conditions (70<THI<79). Severe heat stress conditions with THI greater than 79 were significantly associated with the highest incidence rate of clinical mastitis. - Milk yield decreased starting from a threshold around 73 THI. For fat and protein, thresholds were lower than for milk yield and were shifted around 6 THI units toward larger values in Spain compared with the other countries. Fat showed lower THI thresholds than protein traits in all countries. - The study pointed out that 78.5 and 73.6 THI were the thresholds above which the mortality rate increased significantly for heavy pigs during transport and during pre-slaughtering phases at plant.
R15	Heat stress	- A significant association between year, season and month and the milk quality parameters (somatic cells, bacterial count, fat and protein). The year 2003, the summer and July between summer months July emerged as the most critical periods for all the parameters analysed. - The analysis showed a greater risk of pigs dying during the summer compared with non-summer months when considering both transport and lairage. The month with the greatest frequency of deaths was July while January and March were those with the lower risk of dead both for transport and lairage. - The study on the occurrence of clinical mastitis in dairy heifers pointed out that the summer was the season with higher incidence rate of clinical mastitis (IRCM). July showed the highest value of IRCM. Beyond this, March and June resulted the other months with high values of IRCM. - In semi-arid climates, the combination of heat abatement structures with herd management techniques (such as seasonality of calving) reduces the effects of heat stress on milk yield. Results show the potential for adaptation measures to heat stress at farm scale.
S7	Heat stress	In semi-arid climates, the combination of heat abatement structures with herd management techniques (such as seasonality on of calving) reduces the effects of heat stress on milk yield. Our results show the potential for adaptation measures to heat stress at farm scale.
S9	Heat stress	Model development is needed to improve the assessment of climate change impacts. THI is too general. Animals are individually different, microclimate varies in place and time indoors.
S14	Heat stress	Depending on the THI model, the annual number of days with THI values above THIct increases on average among all farms from 1-7 days in the period 1975-1984 to 9-37 days in the period 2031-2040.
S20	Heat stress	The analysis of the three databases provided several equations which demonstrated and quantified an increase of mortality, reduction of milk yield and a worsening of milk quality in hot environment.
S29	Heat stress	It appears from these results that rumination, milking frequency and milk performance of cows milked by an automatic milking system are affected by a mild HS at pasture.
S30	Heat stress	The analysis of mortality data indicated that the risk of dairy cows to die was higher during heat waves. When a potential prolonged effect of HW was investigated, the model pointed out an extended risk of mortality during the 3 days after the end of the wave. The analysis also indicated a different risk to die in relation to the month of the wave occurrence. HWs occurring at the beginning of summer resulted in greater risk compared with those occurring at the end of the season. Finally, also the length of the wave was as risk factor. Dairy cow mortality increased for each consecutive day within the wave.

nr	Theme	Q3 summary farm relevant
S31	Heat stress	All THI models show increasing THI levels for the national aggregate and all NUTS-3 regions. This implies increasing pressures on livestock production under the assumed climate change scenario. The most plausible results show a loss of 0.6% in annual milk yields at aggregated national level with considerable variation among NUTS-3 regions, which can be reduced by adaptation.
S32	Heat stress	Preliminary observation suggests a different scenario of heat stress tolerance by organic cows than previously reported for cows under conventional intensive management. Considerations with respect to heat stress should also address farm-specific conditions and good farming practices should regard their need for ongoing adaptation at the farm level.
TF7	Heat stress	An analysis of data indicated that the daily THI at which milk production started to decline for the 3 parities and traits ranged from 65 to 76. These THI values can be achieved with different temperature/humidity combinations with a range of temperatures from 21 to 36°C and relative humidity values from 5 to 95%. The highest negative effect of THI was observed 4 d before test day over the 3 parities for all traits. The negative effect of THI on production traits indicates that first-parity cows are less sensitive to heat stress than multiparous cows.
TF10	Heat stress	Milk yield showed an HS threshold around 73 THI_{max} units. For fat and protein, thresholds were lower than for milk yield and were shifted around 6 THI units toward larger values in Spain compared with the other countries. Fat showed lower HS thresholds than protein traits in all countries. Higher/lower producing animals showed less/more persistent production (quantity and quality) across the THI scale. Overall, animals producing in the more temperate climates and semi-extensive grazing systems of Belgium and Luxembourg showed HS at lower heat loads and more re-ranking across the THI scale than animals producing in the warmer climate and intensive indoor system of Spain.
TF18	Heat stress	Dairy cows mortality was greater during heat wave (HW) compared with nHW days. Furthermore, compared with nHW days, the risk of mortality continued to be higher during the 3 d after the end of HW. Mortality increased with the length of the HW. Considering deaths stratified by age, cows up to 28 mo were not affected by HW, whereas all the other age categories of older cows (29–60, 61–96, and >96 mo) showed a greater mortality when exposed to HW. The risk of death during HW was higher in early summer months. In particular, the highest risk of mortality was observed during June HW. Present results strongly support the implementation of adaptation strategies which may limit heat stress-related impairment of animal welfare and economic losses in dairy cow farm during HW.

Table 10 Farm scale results in reports and papers from MACSUR: Farm modelling

nr	Theme	Q3 summary farm relevant
S26	Farm model	Model development, decision support system SOLID-DSS that can be used on organic and low input farms to support forage supply and demand
S27	Farm model	The described integral decision support for sheep farming systems combines simulation and optimization procedures.
S34	Farm model	Farm model Dairy Cant is an empirical model that simulates managements aspects related to milk production and environmental health on dairy farms
S35	Farm model	Modelling parasite risk is presented: how changes in parasite development and survival affect nematode outbreaks in livestock is described
S36	Farm model	A Dynamic LCA model for evaluating the effect of management changes in the whole system to find mitigation potentials in beef production is presented.
S38	Farm model	A farm model study with diets is presented. New dietary strategies that are tested offer promising overall GHG reductions
S8	Farm model	The Index-based Costs of Agricultural Production (INCAP) is presented. INCAP can be used for exploring and communicating possible economic implications related to the impact of climate change; it also informs farmers about adaptation and mitigation costs in their specific environment.
TF1	Farm model	The presented model framework is meant to be used by farmers in due time.
TF17	Farm model	Modelling crop growth under climate change and calculate impact on farms in Ireland is presented. The growth models suggested a decrease in cereal crop yields (up to 9%) but substantial increase in yields of forage maize (up to 97%) and grass (up to 56%) in all regions. The results suggest that there is a regional variability between farms in their responses to the climate change scenario.

Table 11 Farm scale results in reports and papers from MACSUR: Indirect farm scale results

nr	Theme	
TF19	Adaptation	Worldwide costs for adaptation strategies are estimated
R1, 13	Health	Contributes to improve disease modelling
S24	Health	The use of systems-based LCA allowed the effect of individual disease impacts to be quantified and presents scope for application to further diseases (and species).
S12	Heat stress	Classification of heat stress models
R9	Farm	Inventory of farm scale models.
S6	Farm	The LNE model may be useful in assessing the impact of climate change on N use efficiency of dairy cattle.
R11	Model	Report focussed on the accessibility of data for researchers, and mapping the resources available; to do with capacity building, rather than providing findings relevant in the field.
S40	Modeler training	Short courses will no doubt continue to play an important role in modeler training. To make these courses as useful as possible, it would be very helpful to have an overall training program, rather than to treat each short course individually.
S37	Model	Model evaluation of SPACSYS for grassland production, contributes to improve grassland modelling
R2-R7, R10*, R12	Grassland	Contributes to improve grassland modelling (*R10 spec: Report was intended to identify the most appropriate meta-data to be used in online resources informing grassland modellers about existing data sets.)
S3	Grassland	contributes to improve grassland modelling
S16	Grassland	Inventory of mechanistic grass growth models
S39	Grassland	Calibration of grassland models
S4	Grassland	Most grassland models do already include an adequate formulation of the effects of water deficit on photosynthesis and transpiration. At times, this is sufficient to predict the total effect of seasonal drought on herbage growth. In general, however, the models appear to lack the level of realism necessary to reproduce the range of responses observed in the field. The present analysis disclosed deficiencies irrespective of model complexity.
S18	Grassland	Modelling grassland on regional scale for regional adaptation strategies
TF2, 3, 4, 5, 6, 11	Grassland	Improving grassland modelling by ensemble simulations, evaluation; Specifically TF3 and TF4: evaluation of grassland models; TF 6: calibration of grassland models
TF20	Grassland	Contributes to improve grassland modelling
S25	Stakeholders	Explanation of Animal Task Force
S11	Stakeholders	How to exchange knowledge to stakeholders
TF9	Land use	Optimization of regional land use by modelling, to be used by policy makers.
PF1	Grassland	Identify the key challenges for European grassland modelling under climate change.
PF2	Ruminant production systems	This paper 1) provides an overview of how ruminant systems modelling supports the efforts of stakeholders and policymakers to predict, mitigate and adapt to climate change and 2) provides ideas for enhancing modelling to fulfil this role.
PF3	Animal health	Identify gaps in capability in relation to the impacts of climate change on animal health. The need for collaboration and learning across disciplines was highlighted. Systems and health problems indicated the importance of joined up approaches across nations.

Conclusion

The inventory of farm-scale relevant outcomes of the livestock and grassland modelling theme of LiveM presented here, provides an overview of the diverse topics, systems and geographical areas in which LiveM partners work, and signposts those activities of most relevance to farmers and farm advisors. The inventory highlights the dual (and interdependent) roles of the MACSUR knowledge hub, to increase the capacity of modelling to meet stakeholder and societal needs under climate change, and to apply that increased capacity to provide new understanding and solutions at the policy and (the focus here) farm scales. While capacity building work across disciplines is time-consuming and difficult, and to a large extent invisible to stakeholders, such work is vital to ensuring that subsequent scientific outcomes with direct impacts on the real world reflect best practice, and integrated expertise. LiveM has brought together a diverse, multi-disciplinary community of modellers and experimental researchers from across Europe, many of whom had little previous contact or knowledge of the research being undertaken in the other fields and regions represented in the consortium. As a result, position papers and many of the analysed reports focus on essential capacity building, which (if sustained and funded over time) can be expected to i) yield long term improvements in the production of policy and farm ready modelling outputs, and ii) to increase the resilience and flexibility of the livestock and grassland modelling community in Europe to address the needs of stakeholders under climate change. The current report highlights the ongoing contributions of livestock and grassland modellers and researchers in LiveM to improving the adaptability of European livestock production systems, reducing their GHG emissions and providing risk assessments of future change through work at the farm-scale. A future challenge will be to ensure that the understanding gained at this scale is more effectively applied to improve larger scale modelling for policymakers, and that understanding of larger scale climatic, political, social and economic change can be more effectively translated into information and solutions for farmers and their advisors.

Acknowledgements
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References

Links to reports and papers

nr	LINK
R1	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.1/13
R2	http://ojs.macsur.eu/index.php/Reports/article/view/D-L2.1.2/pdf_2
R3	http://ojs.macsur.eu/index.php/Reports/article/view/D-L2.1.1/29
R4	http://ojs.macsur.eu/index.php/Reports/article/view/D-L2.4/162
R5	http://ojs.macsur.eu/index.php/Reports/article/view/D-L2.2/59
R6	http://ojs.macsur.eu/index.php/Reports/article/view/D-L2.3/60
R7	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.3/20
R8	http://ojs.macsur.eu/index.php/Reports/article/view/D-L3.3/166
R9	http://ojs.macsur.eu/index.php/Reports/article/view/D-L3.1/258
R10	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.4.1/65
R11	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.4.2/90
R12	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.3.1/11
R13	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.2.1/14
R14	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.2.3/93
R15	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.2.2/91
R16	http://ojs.macsur.eu/index.php/Reports/article/view/D-L1.5/12
R17	http://ojs.macsur.eu/index.php/Reports/article/view/D-L4.2/94
R18	http://ojs.macsur.eu/index.php/Reports/article/view/L2.3-D1/pdf
S1	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/effects-of-roughage-characteristics-on-enteric-methane-emission-in-dairy-cows/529476C542E73824D0C75E1AF324BD03
S2	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/endemic-sheep-and-cattle-diseases-and-greenhouse-gas-emissions/CB3896F81E3D3FF362B9637AF4E3216D
S3	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/c-and-n-models-intercomparison-benchmark-and-ensemble-model-estimates-for-grassland-production/721FAD75215B8AD406D4B396DAB3B4F9
S4	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/assessing-dairy-farm-sustainability-using-wholefarm-modelling-and-life-cycle-analysis/D0EE42BD8C248FF2960284A625DD911A
S5	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/assessing-dairy-farm-sustainability-using-wholefarm-modelling-and-life-cycle-analysis/D0EE42BD8C248FF2960284A625DD911A
S6	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/lifetime-nitrogen-use-efficiency-of-dairy-cattle-model-description-and-sensitivity-analysis/F085CC65F808FDE1408C8FCD2D03238B
S7	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/heat-stress-effects-in-milk-yield-and-milk-traits-at-farm-scale/A5FC078A1DA8E9563C57F25C7205FF8A

S8	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/an-indexbased-production-costs-system-to-evaluate-costs-of-adaptation-and-mitigation-in-dairy-and-cattle-farming/5A1DB486B43D110EE1BF160E5C6BAC47
S9	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/integrated-modelling-to-assess-optimisation-potentials-for-cattle-housing-climate/FD4E8EEFE59AB9841DA7E15FC89B8E74
S11	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/stakeholder-engagement-and-the-perceptions-of-researchers-how-agricultural-modellers-view-challenges-to-communication/F8539A833EE4CBDD0A6C2CC1D8B85CB0
S12	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/modelling-heat-stress-on-livestock-how-can-we-reach-longterm-and-global-coverage/AA195CAE10E27CAA78F5324C9ED59656
S13	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/simulation-of-enteric-methane-emissions-from-individual-beef-cattle-in-tropical-pastures-of-improving-quality-a-case-study-with-the-model-ruminant/F75238B5956DF1C85FA7BE5CAD34CB33
S14	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/heat-stress-impacts-on-cows-in-a-case-study-landscape-measured-by-an-integrated-modelling-framework/755A79377F2E27D212E08DAD435CF4B7
S15	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/exploring-grassbased-beef-production-under-climate-change-by-integration-of-grass-and-cattle-growth-models/D560B3E3704A0CB8C7F2AA12B62E3212
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S17	https://www.cambridge.org/core/journals/advances-in-animal-biosciences/article/effect-of-season-month-and-temperature-humidity-index-on-the-occurrence-of-clinical-mastitis-in-dairy-heifers/012FFB1D672F44ABB6E57D17B21808B1
S18	http://ojs.macsur.eu/index.php/Reports/article/view/SP3-6/51
S19	http://ojs.macsur.eu/index.php/Reports/article/view/SP3-11/58
S20	http://ojs.macsur.eu/index.php/Reports/article/view/SP3-3/47
S21	http://ojs.macsur.eu/index.php/Reports/article/view/SP3-1/45
S22	https://www.cambridge.org/core/services/aop-cambridge-core/content/view/9C74832649885EF8078270DAA8DED739/S2040470014000521a.pdf/pasture-harvest-carbon-sequestration-and-feeding-potentials-under-different-grazing-intensities.pdf
S23	https://www.cambridge.org/core/services/aop-cambridge-core/content/view/B37EAB4600EF207C4F63DFEC7326BC92/S2040470014000533a.pdf/further-effects-of-forage-on-greenhouse-gases-estimated-by-dairycant-for-dairy-farms.pdf

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S25	DOI: https://doi.org/10.1017/S2040470014000375
S26	DOI: https://doi.org/10.1017/S2040470014000387
S27	DOI: https://doi.org/10.1017/S2040470014000399
S28	DOI: https://doi.org/10.1017/S2040470014000405
S29	DOI: https://doi.org/10.1017/S2040470014000417
S30	DOI: https://doi.org/10.1017/S2040470014000429
S31	DOI: https://doi.org/10.1017/S2040470014000430
S32	DOI: https://doi.org/10.1017/S2040470014000442
S33	DOI: https://doi.org/10.1017/S2040470014000454
S34	DOI: https://doi.org/10.1017/S2040470014000466
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S37	DOI: https://doi.org/10.1017/S2040470014000508
S38	DOI: https://doi.org/10.1017/S204047001400051X
S39	DOI: https://doi.org/10.1017/S2040470014000545
S40	DOI: https://doi.org/10.1017/S2040470014000557
PF1	http://www.sciencedirect.com/science/article/pii/S0048969716310750
PF2	http://www.sciencedirect.com/science/article/pii/S0308521X16301287
PF3	http://www.sciencedirect.com/science/article/pii/S001393511630319X
TF1	http://www.sciencedirect.com/science/article/pii/S1574954115001703
TF2	http://www.sciencedirect.com/science/article/pii/S1161030116301204
TF3	https://link.springer.com/article/10.1007%2Fs13593-014-0271-0
TF4	http://www.sciencedirect.com/science/article/pii/S0167880915300670
TF5	http://www.sciencedirect.com/science/article/pii/S1161030116301204
TF6	http://www.sciencedirect.com/science/article/pii/S1574954115001569
TF7	http://www.sciencedirect.com/science/article/pii/S0022030213007467
TF8	https://www.cambridge.org/core/journals/animal/article/div-classtitleseasonal-variations-in-the-composition-of-holstein-cows-milk-and-temperaturehumidity-index-relationshipdiv/C3E37CBA9E01BB78D1ED4F61D3B12A91
TF9	http://www.sciencedirect.com/science/article/pii/S0165188914003108
TF10	http://www.sciencedirect.com/science/article/pii/S0022030216001715
TF11	http://www.sciencedirect.com/science/article/pii/S0168192315007285
TF12	http://www.sciencedirect.com/science/article/pii/S0308521X16301536
TF13	http://www.sciencedirect.com/science/article/pii/S0308521X16300014
TF14	http://www.sciencedirect.com/science/article/pii/S0378429014000501
TF15	http://www.int-res.com/abstracts/cr/v65/p71-86/
TF16	http://networks.iamz.ciheam.org/mountpast2016/pdfs/OptionsMediterraneennesA116-online.pdf

TF17	https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/div-classtitleirish-farms-under-climate-change-is-there-a-regional-variation-on-farm-responsesdiv/166D3D2D3989B05DB311F785A3414AF3
TF18	http://www.sciencedirect.com/science/article/pii/S0022030215003057
TF19	http://iopscience.iop.org/article/10.1088/1748-9326/10/9/094021/meta;jsessionid=2B6BB21DFCD6A6334840A9601A4B4DB6.c4.iopscience.cld.iop.org
TF20	http://www.sciencedirect.com/science/article/pii/S0304380016301661