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Deliverable title: Synergies and trade-offs between adaptation and mitigation at the regional scale

Abstract:

This paper describes synergies and trade-offs between adaptation and mitigation at the regional scale. Firstly, it provides a table which identifies relevant adaptation and mitigation options for specified systems in specified regions. Second, it discusses the synergies and trade-offs between these adaptation and mitigation options for those regions.

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1. Introduction

AnimalChange will provide scientific guidance on the integration of adaptation and mitigation objectives and design sustainable development pathways for livestock production in Europe, in Northern and Sub-Saharan Africa and Latin America. This report (Deliverable 12.2) is part of Work Package 12 of AnimalChange. Work Package 12 is combining information from field/animal level, farm level and regional/global level to design adaptation/mitigation combinations suited to the levels of vulnerability and mitigation potentials in the main regions/systems included in the project and to assess the likely effects of implementing these mitigation and adaptation options. The current Deliverable describes relevant options for livestock systems in different regions and identifies the synergies and trade-offs between adaptation and mitigation at the regional scale (landscape, farming system).

Adaptation and mitigation strategies in most regions are largely disconnected, generating the risk of trade-offs. In general, developed countries are more oriented towards mitigation options and developing countries are more oriented towards adaptation options. Adatation and mitigation strategies consist of one or more options that aim to either reduce the emissions of greenhouse gases or to adapt to future climatic conditions or both. Mitigation options are options which reduce the emissions of greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from livestock production systems. Adaptation options describe ways for livestock production systems to adapt to future climatic conditions (global warming, larger climatic variability and increased frequency and severity of droughts and floods). Depending on the adaptation option, the systems can be affected with different consequences:

- Resilience: the system comes back to the original state after the climate change event (e.g. drought stress) has terminated,
- Resistance: the system resists the stress i.e. does not change during the stress (e.g. does not reduce yield),
- Prevention: the adaptation measure prevents stress to occur (e.g. irrigation, cooling).

Often in situations of improved productivity, adaptation leads to reduction of greenhouse gas emissions per unit of product and synergies with mitigation are therefore implicit.

The aim of this study is to identify relevant adaptation and mitigation options for specified systems in specified regions and to discuss the synergies and trade-offs between these adaptation and mitigation options for those regions.

Chapter 2 describes the methods used for this study. Chapter 3 provides a ranking of options at the regional scale done by local experts. Chapter 4 describes these options and discusses synergies and trade-offs. Finally, Chapter 5 provides some concluding remarks.

2. Materials and methods

The most relevant adaptation and mitigation options at the farm scale were identified by local experts in several regions in 2013 and the beginning of 2014. Experts were asked to identify for their particular farm types representative of the region the most relevant options based on a short-list of options defined by the AnimalChange partners. Local experts could also add options. The relevance of the options has been identified using expert judgement of the project partners in the study regions of AnimalChange in Europe, Africa and Latin America. For Europe the countries were Ireland, France, the Netherlands, Portugal, Denmark, Scotland, Spain and Italy. For Arica: Senegal, Burkina-Faso, Mali, Cape-Town and Pretoria regions. For Latin America: 'Campos' (South Brasil), 'Cerrado' (Central Brasil), biomes and pastures after deforestation in Eastern (Belem) Brasilian Amazon, pastures after deforestation in French Guiana.

Since only the most relevant options were chosen, sometimes options that could be relevant in several parts of the world only appear on the list for a specific region. That does not mean that they cannot be important in other regions. It just means that in those other regions other options were considered to be more relevant. The ranking led to regional lists of the most relevant adaptation and mitigation options. These could be combined to design relevant mitigation and adaptation packages.
The document describes both mitigation and adaptation options at the field / animal / farm level and mitigation and adaptation options at the regional level. An example of the latter is livestock mobility where animals move outside the farm border and within a region or between regions. Change in livestock systems is another example. Of course in a certain region, both the options at the field / animal / farm level and the additional options at regional level can be carried out.

An analysis of synergies and trade-offs between options has been carried out based on information generated by experts within AnimalChange, and collected through literature review and expert consultations. The information originates from experiences at field/animal level, farm level and regional level. It also builds on earlier AnimalChange work (Van den Pol-van Dasselaar, 2012). Finally, within AnimalChange there have been many meetings and discussions on both mitigation and adaptation options, which have been relevant for this deliverable.

3. Adaptation and mitigation options specified per region

Table 1 summarises the most relevant adaptation and mitigation options for different regions in the world as identified by local experts. As said before, when a certain option is not mentioned in a certain region, this does not mean that it is not relevant or feasible there. It simply means that in that particular region other options were considered more relevant. The adaptation and mitigation options mentioned in Table 1 are extensively described in the next chapter.

Table 1. Most relevant adaptation and mitigation options for different regions in the world as identified by local experts.

Farm type	AEZ	Region	Fertilisation rate	Water management (water storage for livestock)	Water management (irrigation, drainage)	Change the grazing management	Use of mixtures of plant species	Use of plants more resistant to drought, flooding, pests and diseases	Clean the pasture from unwanted species	Feed storage	Supplemental feeding	Cooling of animals (housing)	Animal breeding (local breeds)	Animal breeding (change breeds)	Restoring degraded lands	Replacement rate cattle	Shifts in livestock systems	Livestock mobility	Fertilisation rate	Nitrification inhibitors	Grass-legume swards	Legumes in the rotation	Restoring degraded lands	Improving pastures	Improving roughage quality	Feeding more maize and less grass	Feeding more fat	Additive nitrate	Balancing amno acids and reduce CP	Replacement rate cattle	Cover slurry stores	Manure acidification	Anaerobic digestion	Agroforestry	Genetic improvement in cattle	Change the grazing management	Integrate livestock and crop production	Reducing age at first calving
			Adaptation options - Adaptation options - Adaptation options																Mitigation options - Mitigation options - Mitigation options - Mitigation options																			
Mixed dairy	Maritime	Europe	x		x						x	x							x	x						x	x	x				x	x		x			x
Mixed dairy	Continental	Europe			x		x			x									x	x						x	x	x				x	x		x			x
Mixed dairy	Mediterranean	Europe			x		x			x	x								x	x						x	x	x				x	x		x			x
Mixed beef	Maritime	Europe								x									x	x						x	x	x				x	x		x			x
Mixed beef	Continental	Europe			x		x			x									x	x						x	x	x				x	x		x			x
Grassland dairy	Maritime	Europe	x		x						x		x						x	x	x			x						x					x	x		x
Grassland beef	Maritime	Europe	x		x						x		x						x	x	x			x		x	x			x					x	x		x
Grassland beef	Continental	Europe			x		x			x									x	x	x			x	x	x	x			x					x	x		
Grassland beef	Mountain	Europe								x									x	x	x			x	x	x	x			x					x	x		
Grassland sheep	Mountain	Europe								x									x	x	x			x	x											x		
Grassland sheep	Mediterranean	Europe																	x	x	x			x	x											x		
Pig	N-Eu	Europe	x		x		x			x									x	x									x		x	x	x					
Pig	S-Eu	Europe		x							x	x	x	x					x	x									x		x	x	x					
Industrial beef	Sub-humid	Brazil, Cerrado	x							x	x		x				x																					
Intensive dairy	Sub-humid/humid	Brazil	x		x						x						x		x			x	x	x										x		x	x	
Intensive beef	Sub-humid/humid	Brazil															x		x			x	x	x										x		x	x	
Dairy / beef on pasture after deforestation	Sub-humid/humid	Brazil, Amazon															x		x			x	x	x										x		x	x	
Dairy on pasture after deforestation	Sub-humid/humid	Brazil, Amazon					x				x			x			x																					
Beef on pasture after deforestation	Sub-humid/humid	Brazil, Amazon	x				x							x			x																					
Extensive beef	Sub-humid/humid	Brazil								x	x						x		x				x	x	x											x	x	
Extensive beef	Sub-humid	Brazil, Cerrado								x	x						x		x				x	x	x											x	x	
Crop livestock	Semi-arid grassland	Burkina Faso																	x			x		x									x					
Crop livestock pastoral	Sub-humid	Burkina Faso																	x			x		x									x					
Semi-intensive	Sub-humid/humid	French Guiana																	x			x								x						x		
Extensive	Sub-humid/humid	French Guiana																	x			x								x						x		
Extensive mixed dairy	Mixed rainfed, humid/subhumid	Kenya, Africa	x				x						x	x				x																				
Extensive beef	Semi-arid grassland	South Africa				x			x		x				x	x			x				x	x	x					x						x		
Crop livestock	Semi-arid grassland	Senegal						x					x				x	x																				

4. Synergies and trade-offs between adaptation and mitigation

This chapter provides information on the options in Table 1 of the previous chapter and discusses both synergies and trade-offs that are generally applicable and some site-specific synergies and trade-offs. The chapter starts with a number of options that are identified by local experts as being relevant for both adaptation and mitigation in their region (4.1). Thereafter options that are identified for, respectively, adaptation only (4.2) and mitigation only (4.3) are discussed.

4.1. Adaptation/mitigation options

There are a number of options which have been identified as relevant for both adaptation and mitigation by local experts (Table 1). Generally, interventions aiming at improving natural resource management can have both mitigation and adaptation potential, e.g. by improving nitrogen use efficiency or reducing water dependence (Jarvis *et al*. 2011). In developing countries, such interventions can contribute to increased productivity and therefore contribute as well to food security (Gerber *et al*, 2013).

The following options, described below, fall into this category and are often referred to as win-win options:

- Fertilisation rate
- Change the grazing management / optimal grazing
- Animal breeding / genetic improvement in cattle
- Restoring degraded lands / improving pastures
- Replacement rate cattle
- Shift in production systems (e.g. agroforestry / integration of livestock and crop production)

<u>Fertilisation rate</u>
Appropriate use of fertilisers and manure will lead to productive fields. An improved productivity may increase resistance to climate change (Bryan *et al*., 2011). Appropriate fertilizer/manure N use also has a high mitigation potential. Measures which lead to an increased N efficiency will lead to lower N_2O emission intensity (i.e. per kg of product). The efficiency of N utilisation can be improved by adjusting the application rates to local conditions (Schulte *et al*., 2011) and to local fertilisation advices. When application rates or the moment and method of application are suboptimal and improved with improved farming practices, N fertilisation may be reduced without loss in production which will lead to less GHG emissions. Optimal fertiliser application will lead to minimal GHG emissions and less nutrient losses. Optimal fertiliser application includes split fertilisation (avoid high N in soil), precision fertilisation (avoid high-risk areas) and optimal timing (avoid high-risk times). Furthermore, the application technique itself will be of influence, e.g. injection or other techniques to incorporate manure into the soil will affect GHG emissions. Manure

run-off should be avoided just as fertilisation in wet conditions since this will lead to nutrient losses.
However, there is also evidence that in cereals higher fertilisation actually increases susceptibility to higher temperatures and droughts (e.g. Trnka *et al.*, 2012). Due to climate change, an altered N fertilisation strategy may be needed to keep fertilization optimal and to improve productivity, increasing the systems resilience to climate change. This is especially true in situations of underfertilisation such as for example in Sub Saharan Africa. In tropical areas low-input crop-livestock systems dominate (Herrero *et al*., 2010). In Latin America grazing low-input systems dominate but they are not integrated to cropping. Manure is the main resource for maintaining soil fertility, crop productivity and livestock feed production (Rufino *et al*., 2007). In these systems the high temperatures increase the risk and the intensity of gaseous N and C losses (Vayssières and Rufino, 2012). In dry areas (e.g. Sahel, Senegal-Burkina Faso), it is expected that higher temperatures will further increase these losses (ammonia emissions in particular) during the biomass recycling (crop-livestock-manure-crop). Adapted manure management strategies are needed to better conserve N and C (Tittonell *et al*., 2010). For instance manure storage using a polyethylene cover or rapid and shallow manure incorporation are relevant options to reduce losses and increase the livestock (and crop) productivity and reduce its variability (more organic matter in soils). In areas where rain will increase (possibly Indian Ocean, Madagascar, South Africa), there are good chances that runoff and leaching will increase. Adapting manure management practices, like manure composting (El Kader *et al*., 2007) and split application (with adapted storage conditions), may be relevant to improve productivity and production stability in this context. A trade-off of the option fertilisation rate is that there will be economic constraints for implementation in developing countries.

<u>Change the grazing management / optimal grazing</u>
Annual forage productivity is worldwide often greater in grazed grasslands than in ungrazed grasslands or, in contrast, than in overgrazed grasslands. Grazing will increase biodiversity and in general lead to less weeds. It can lead to invasion control and stimulate grass tilling and improvement of seed germination (Silvestri *et al*., 2012). Also, in most cases, grasslands with appropriately managed grazing store more soil C than ungrazed natural grasslands (Eagle *et al.*, 2012). Grazing can result in higher soil C than ungrazed grass due to more rapid turnover of shoot material and also due to changes in species composition (Rees *et al.*, 2005). Grazing leads to more N_2O emissions (especially from urine patches) and less CH_4 emissions than zero-grazing. The CH_4 reduction is related to less manure storage. There are different views on the overall effect of grazing on total GHG emissions. Some promote extending the grazing season (e.g. Schulte *et al.*, 2011), while others claim that restricted grazing is the optimal situation (Van den Pol-van Dasselaar *et al*., 2008). A precise delineation of conditions and effects on GHG emission seems required to make such a distinction. Optimal grazing also includes reduction in field stocking rates when soils are wet and adapting the length of the grazing period to the forage available. Smith *et al.* (2008) conclude that the influence of grazing intensity is not well established and that this depends on the many types of grazing practices employed and the diversity of plant species, soils and climates involved.

Animal breeding (local breeds/change breeds) / genetic improvement in cattle

More heat tolerant breeds are needed for those farming systems where the environment cannot be controlled through the building design of the animal houses and shelters or where animals spend considerable time outdoors. The introduction of more heat tolerant breeds could replace native bred livestock or replace breeds that have been bred solely for high productivity. Since climate is expected to become more variable in many areas, it may also be necessary for some farming systems that animals become robust to variable conditions and greater variation in feed supply and quality. A first step would be to identify local breeds that have adapted to local climatic stress or variable feed resources. A second step would be to improve local breeds through cross-breeding with heat tolerant breeds, and select for better adapted animals. With climate change also an increased attention is needed for breeds which are more resistant to emerging diseases in a certain area as a result of climate change, or to obtain animals which combine resistance to local pressure of disease with high productivity. These may or may not be local breeds. Animal breeding should lead to improved animal health. Under global warming, gastro-intestinal parasites will be amplified. The parasite species already present in currently relatively cool areas will be favoured and at the same time the species currently present at warmer areas (like Haemonchus sp., very pathogenic) will probably expand more to the currently relatively cool areas (Wall and Morgan, 2009). Improvements in local breeds should lead to increased productivity per animal as well as improved feed use efficiencies for the resources available (Bryan *et al*., 2011).

A final remark is that besides improved local breeds or changed breeds as a result of their drought tolerance, animal breeding in general leads to more productive animals. Genetic improvement may therefore have impact on GHG emissions by increasing production efficiency and thus decreasing emissions per unit of product. When more productive animals have the same tolerance to heat stress as less productive animals, animal breeding can lead to less GHG emissions and a higher productivity by selection for a higher feed intake, a higher feed conversion efficiency and a higher productivity. Also selection for animals with lower emissions per unit of dietary intake, given a certain genetic merit for feed intake, feed efficiency and production, may lead to a lower CH_4 emission. The former type of breeding would be more a continuation of the on-going process of genetic improvement that already has been taken place during the last decades in intensive systems. The latter is momentarily under investigation and it is still uncertain how much reduction in CH_4 can be achieved by selecting for individuals which perform comparable to others but demonstrate low CH_4 production in the rumen. Improvement of the genetic merit of animals is an option for the medium to long-term (Schulte *et al*., 2011).

Restoring degraded lands / improving pastures

Avoiding soil degradation or recovering of farm soil is in many parts of the world one of the best mitigation options. In Brazil, for example, it is estimated that there is a very large area of degraded soils (Bai *et al.*, 2008). Soils are often degraded due to excessive or improper use, erosion, the loss of organic material, high salt contents or low pH. Soil productivity can be recovered by planting pasture, proper nutrient selection, the application of organic substrates such as some wastes or composts, less tillage (direct planting), increasing legumes, keeping farm wastes on the soil, moisture retention, crop-livestock systems and adjusting the stocking rate to the carrying capacity of the land grazed. Increased productivity will lead to prevention of possible effects of climate change and restoring degraded lands is thus also an adaptation option. Actual implementation of this option requires not only knowledge of the measure but also social barriers have to be solved e.g. cash to be able to buy the necessary resources or alternatives when the stocking rate has to be adjusted. Pasture reclaiming or pasture recovery is seen as one of the main components regarding mitigation in countries like Brazil. Restoring of degraded lands is also an important option in Africa. It will lead to less GHG emissions through soil carbon sequestration and a vital agriculture. It also can prevent erosion. Trade-offs are the energy needed for restoring degraded lands / improving pastures and the high associated costs.

<u>Replacement rate of cattle</u>

Good agricultural practices may lead to a decrease in replacement rates of cattle. This means that less calves are needed for a certain production. This will lead to less CH_4 emissions of the total herd while maintaining herd production. This could also be achieved by an increased fertility of animals which will lead to a reduced number of followers required (Chadwick *et al*., 2007). Increasing the longevity of cattle is an attractive option for farmers, since it will increase the profitability of the farm and lead to less nutrient losses. This option only works, however, if there is a solution for the surplus cattle, e.g. via a coupling with semen sexing. If the surplus cattle are fattened to produce meat, they will remain responsible for emissions, though on another production unit.

<u>Shift in production systems (e.g. shifts in livestock systems / integration of livestock and crop production / agroforestry)</u>

Changing from one livestock system to another is an option to adapt to climate change. The optimal livestock system may depend on criteria like length of the growing season, temperature (average and variation) and rainfall (average and variation) since certain systems operate in certain ranges. Integrating livestock and crop production systems is another option to adapt to climate change. In Latin America for example, beef production is combined with crop production to improve soil fertility on the one hand and spread risks on the other hand. Choosing for the optimal system often also leads to a decrease in greenhouse gas emissions (e.g. Havlik *et al.*, 2014). In Western Africa for example, both mixed crop-livestock systems and pastoral systems depend on cropping systems because crop residues are important feed resources determining livestock productivity or substituting for pastures during the dry season. Due to climate change, farmers often change their crop varieties: for instance long cycle varieties of millet (matye) to short cycle varieties of millet (pod) if long periods of drought occur. And in more extreme conditions farmers replace maize by millet and sorghum. These options are very important for stabilizing livestock productions. If climate change is very intense like in Western Africa it is possible that livestock systems will move from large ruminant systems to small ruminant systems, and even that crop systems will be replaced by livestock systems (Jones and Thornton, 2009). Livestock is a more resilient activity, especially when mobility is possible. A trend that has been observed in East and West Africa over the last 3 decades is the development of small ruminants and

camels. Small ruminants and camels can be more resistant and have higher mobility than cattle.
Agroforestry and silvopastoral systems (a combination of tree and crops) have a mitigation potential through increased soil carbon sequestration. They will also lead to increased resilience to climate change due to improved soil conditions and water management, reducing evapotranspiration and allowing for better water control and a higher water holding capacity of the soil. Finally, agroforestry may lead to greater yields on adjacent cropland due to improved rainwater management and reduced erosion (Vergé *et al.*, 2007; Bryan *et al.*, 2011).

4.2. Adaptation options

Options from Table 1 that have been identified by the local experts as most relevant for adaptation only in their region are described below:

- Water management (water storage for livestock; irrigation, drainage)
- Use of mixtures of plant species
- Use better adapted plant species (use of plants more resistant to drought, flooding, pests and diseases / clean the pasture from unwanted species)
- Feed storage
- Supplemental feeding
- Cooling of animals
- Livestock mobility

<u>Water management (water storage for livestock)</u>
This is a useful adaptation option in situations where often dry periods occur. Water storage possibilities should be created and they should be filled in periods with enough water available. For this option, it should be kept in mind that climate change may also influence the amount of water available. Trade-offs of this option are the costs and labour associated with this option.

<u>Water management (irrigation, drainage)</u>
In situations of water shortage or situations of extreme rainfall, management options, like irrigation, contour farming, terraces, mulching, ditches and grass strips can be used to harvest more water, to conserve water and increase soil moisture content if needed, and to prevent runoff and soil erosion, and in that way act as options to adapt to climate change (Biazin *et al.*, 2012). For situations of water shortage, this option assumes that there is water available to store, either from other regions or from wetter periods. It should be kept in mind that climate change may also influence this amount of water available. Water management will reduce the variability in production due to better soil quality and a better (rain) water management, and hence lead to increased yields.
In situations where irrigation is possible, it will lead to higher yield and less variability in yield (Bryan *et al*., 2011) and thus irrigation is an adaptation option. It also contributes to mitigation per unit of product produced. When irrigation is needed and water is scarce, irrigation during the night will lead to higher water use efficiency than irrigation during the day. In situations where irrigation is energy intensive more CO_2 emissions may occur which may counteract the positive mitigation potential as

described above. Irrigation and drainage increase the water use efficiency, but they also have associated costs.

Use of mixtures of plant species

Mixed swards in general, and especially mixed swards with legumes, offer an important option for adaptation to expected climatic change. Grass-legume swards have important yield advantages compared to monocultures of either grasses or legumes (Kirwan *et al*., 2007; Lüscher *et al*., 2008; Nyfeler *et al*., 2009; Finn *et al*., 2013). Ecological theories not only predict higher yields of mixed swards, but also that they can better deal with climatic variability and stress and that they show higher resilience after cessation of stress (insurance hypothesis, Naeem and Li, 1997; Yachi and Loreau, 1999). Moreover, legume species are well-adapted to future conditions that reflect global climatic change, since they have higher temperature optima than grasses and strong positive responses to elevated CO_2-concentrations (Lüscher *et al*., 2004; Soussana and Lüscher, 2007). Lüscher *et al*. (2013) showed that legumes seem to be especially drought resistant.

Introduction of greater diversity into pastures (i.e. forage mixtures) will not only improve biodiversity but also increase N-use efficiency and productivity due to transgressive overyielding (when mixtures outperform the best monoculture) (Kirwan *et al*., 2007). Through symbiotic N_2 fixation, legumes have access to the unlimited nitrogen source of the atmosphere. N-input into the ecosystem can be as high as 100 to 400 kg ha^{-1} yr^{-1} (Carlsson and Huss-Danell, 2003; Ledgard and Steele, 1992; Nyfeler *et al*., 2011; Zanetti *et al*., 1997). Through this N-input legumes can contribute to adaptation as the option of adapted N-fertilization mentioned above. In addition, the energy demand of symbiotic N_2 fixation is covered by photosynthesis and, thus, is greenhouse gas neutral, in contrast to the production of fertiliser N.

Di Falco *et al*. (2010) also found that increasing the variety diversity increases productivity. Plant genetic resources contain traits that will allow crops to cope with climate change, pests and diseases, as well as to increase crop yields to feed the growing human population (Vergé *et al*., 2007). According to Letourneau *et al*. (2011) biodiversity leads to a reduction in crop damage and an enhancement of natural enemies of herbivores.

Use the correct plant species

When better adapted plant species are used, this will lead to more productive fields. An improved productivity may increases resilience to climate change (Byran *et al*., 2011). This can be reached via e.g. using plants that are more resistant to drought, flooding, pests and diseases or via cleaning of the pasture from unwanted species.

Feed storage

An increase in seasonal variation in roughage feed supply as a result of a changing climate can be counteracted by conserving surplus production during another part of the year (feed storage, e.g. hay or silage). In this way seasonal variations in roughage feed supply are buffered by conservation methods. Conserved roughage could either originate on-farm or be bought on the market. A trade-off are the associated costs.

Supplemental feeding

In situations with a lack of availability or a loss in forage quality and quantity, supplemental feeding can be used to maintain animal productivity. This adaptation option will lead to changes in the balance of feed sources in livestock rations (e.g. often more cereals in the ration) and affect manure production and related N and CH_4 emissions. Furthermore, supplementation will increase costs and might lead to less profit for the farmer and could also have implications for soil C. Supplemental feeds will usually have to be bought by the farmer and can come from crop production (feeding whole crops) or from by-products of the feed industry or from crop residues. Supplemental feeding could also come from buffer grazing areas in the regions which are used to cope with a possible drought.

Cooling of animals

In situations of heat stress, cooling of animals is desirable. Mechanical cooling can best be done in confinement where the livestock is concentrated in relatively small areas. Natural cooling by providing shadow via a simple shelter or roof also reduces the effects of excess heat. The ventilation in buildings could be improved and additional equipment could be installed in buildings and/or outdoor areas like cooling pads, fans systems and water sprayers. Cooling of animals during transport may also be considered here. Cooling of animals increases animal health and animal welfare. In situations of heat stress, it is important to ensure adequate access to water to aid the thermoregulation of the animals.

Livestock mobility

Livestock mobility is an important adaptation factor in some regions. Herds move from extreme dry situations or extreme wet situations (e.g. waterlogged fields) to more favourable areas. These strategies are inherent to many agro-pastoral systems in some of the most vulnerable regions like the Mediterranean and Sub-Saharan Africa. Mobility remains the most important adaptation to spatial and temporal variations in rainfall for the extensive pastoralist, and in drought years many communities make use of fall-back grazing areas unused in ‘‘normal’’ dry seasons because of distance, land tenure constraints, animal disease problems, or conflicts. However, encroachment on and individuation of communal grazing lands and the desire to settle to access human services and food aid have severely limited pastoral mobility (Morton, 2007), pointing toward policy oriented adaptations at the landscape level rather than technical adaptations. Typical points of attention in livestock mobility are corridors for migration, water points and legislation.

4.3. Mitigation options

Options from Table 1 that have been identified by the local experts as most relevant for mitigation only in their regions are described below:

- Nitrification inhibitors
- Legumes (grass-legume swards, legumes in the rotation)
- Improving roughage quality
- Feeding more maize and less grass
- Feeding more fat

- Additive nitrate
- Balancing amino acids and reduce CP
- Cover slurry stores
- Manure treatment (manure acidification, anaerobic digestion)
- Reducing age at first calving

Nitrification inhibitors

There are many effects of type of fertiliser on GHG emissions. Peak values in (labile) soil N should be avoided. The use of nitrification inhibitors can strongly reduce both N_2O emissions and nitrate leaching (e.g. Di and Cameron, 2012). Nitrification inhibitors can artificially be added. There are also some inhibitors available, which are produced naturally by plants. They are promising for reducing N_2O emissions from intensive livestock production systems, but result in limited benefits to the producer apart from reducing N losses. The use of urease inhibitors to decrease N_2O emissions may increase ammonium accumulation and consequently, increase nitrate leaching and NH_3 volatilization (Hristov *et al*., 2013).

Grass-legume swards

Forage based systems utilising perennial legumes (e.g. white clover, red clover and alfalfa) may reduce the need for nitrogen fertilisers and hence could significantly decrease GHG emissions associated with the manufacture and use of artificial nitrogen fertilisers (Schulte *et al.*, 2011). It is possible that GHG emissions from legume-based pastures will be lower than from N-fertilised pastures with the same productivity, because the former may avoid peaks in the concentration of protein in the herbage associated with fertiliser applications and because the N fixation in legumes tends to decrease as the availability of soil mineral N increases. In that way a buffer mechanism is provided against fluctuations in soil mineral N. Indeed, comparisons between grass-based and grass/clover-based systems in Ireland have shown a 50% decrease in N_2O emissions for the grass/clover system without any impact on milk yields (Li *et al.*, 2011). Also both N utilisation and total yields in grass-legume mixtures have been shown to be optimised relative to monocultures (Kirwan *et al.*, 2007; Nyfeler *et al.*, 2009; Nyfeler *et al.*, 2011). This is due to a higher degree of niche occupation within these ecosystems, resulting in transgressive overyielding and greater N utilisation between grass and legumes throughout the growing season.

Legumes in the rotation

Improved crop/fallow rotation or rotation with legumes will lead to short term losses due to reduced cropping intensity. However, in the medium- to long-term increased soil fertility and yields are expected due to N fixing in soils. Furthermore, the improved soil fertility and water holding capacity may increase resilience to climate change. The mitigation potential can be high, particularly for crop rotation with legumes (Bryan *et al.*, 2011). Crop rotation may also lead to an improved grass quality which in turn leads to less CH_4 emissions from enteric fermentation, although there might be a trade-off with soil organic carbon sequestration.

Improving roughage quality

The quality of the different roughages and the type of roughage affects CH_4 emissions. Fermentation of sugars and cell walls lead to more CH_4 than fermentation of starch and proteins. Fermentation products like organic acid, and fat lead to little or no CH_4. Sugars provide in most conditions even more CH_4 than cell walls (Bannink *et al.*, 2010). Where starch (maize) and protein (soya) are not degradable in the rumen, they will not produce CH_4. When degraded in the intestines of dairy cattle, they will provide energy for milk production.

In many parts of the world, the quality of the roughage fed to the animals is poor. Improving roughage quality leads to a higher roughage intake by ruminants, an altered chemical composition (more protein, less cell walls, more degradable cell walls), an improved total digestibility of the components and hence a higher feeding value, leading in turn to a higher animal production (Valk *et al*., 2000). Model simulations demonstrated that an improved grass quality leads to less CH_4 emission (Bannink *et al*., 2010). Grass quality can be improved by management, in particular by a more optimal application of fertiliser and manure, and by a more optimal cutting regime and conservation measures. A higher grass quality as a result of a higher N fertilisation and early cutting at low yields leads to less CH_4 emission. In contrast, a lower grass quality as a result of less N fertilisation (with the aim to reduce N_2O emission) or mowing at a higher dry matter yield per ha leads to a higher CH_4 emission (Bannink *et al*., 2010) counterbalancing the sparing effect on N_2O emission. Furthermore, grass quality can be improved by inoculation, chemical treatment and/or mechanical treatment when harvesting and ensiling.

Feeding more maize and less grass

Silage maize is a fodder which results in relatively low enteric CH_4 emissions due to the high starch content (Tamminga *et al.*, 2007). Increasing the percentage of maize in the ration leads to less N and P excretion and less CH_4 emissions. However, at regional level, a systematic increase of maize in the ration could lead to land use change and displacement effects. Vellinga and Hoving (2011) estimated that the mitigation of methane emissions can be offset by land use change. In particular, soil organic carbon (SOC) loss associated with maize production when compared with either pasture or a broad range of other tillage systems is high. Ceschia *et al*. (2010) reported ranges from 4 – 6 t C ha^{-1} yr^{-1}. Although such effects may partly off-set the reduction in CH_4 emission achieved on the short term, the long term effects can remain beneficial.

Feeding more fat

In general, CH_4 emissions are lowest with diets low in sugar, high in starch, high in protein and high in fat. Fat is not fermented in the rumen and as such delivers no CH_4. Fat is digested in the intestine and delivers a lot of energy to the ruminant. There is a substantial body of evidence that feeding dietary lipids can decrease CH_4 production in the rumen, the effect coming both from direct inhibition of rumen methanogenesis and from replacing part of the dietary carbohydrates (when included, lipids usually replace concentrates), which are the primary substrates that lead to CH_4 formation. There are limits in increasing the proportion of fat in the diet; negative effects on fibre degradation should be prevented. However, the risk with lipids lies in the potential negative effect on feed intake and animal production, specifically when total fat in the diet exceeds 5 to 6 percent (DM basis) (Hristov, 2013).

Additive nitrate

It has been shown that adding nitrate to the ration invariably leads to strongly reduced CH_4 emissions (Van Zijderveld *et al*., 2010). Nitrate becomes reduced to nitrite and subsequently ammonium, extracting hydrogen from the rumen environment which can no longer be used as a substrate by methanogens. A disadvantage of adding nitrate is that the N excretion increases, especially in rations with high protein contents. On the other hand, adding nitrate to rations with very low protein content may lead to an improved digestibility of the whole ration and an improved feed efficiency. Nitrate addition may be applied as an alternative to urea addition which is already practised under many production conditions. A further notable limitation to the use of nitrate is the fact that with high dosage the intermediate nitrite may accumulate and become absorbed into blood where it has a toxic effect. In parts of the world, the associated costs of adding nitrate to the ration will be a constraining factor.

Balancing amino acids and reduce CP

In general, CH_4 emissions are lowest with diets low in sugar, high in starch, high in protein and high in fat. Low protein diets limit N-excretion. At the same time protein degraded in the rumen and fermented by micro-organisms delivers relatively less CH_4 compared to all carbohydrates. This means that high-protein diets may be emitting low amounts of CH_4.
Knowing that CH_4 emissions can be influenced by adapting the dietary composition and feeding strategy, a precise analysis of the different components of feed will help in optimizing the ration not only with respect to energy value and ruminant productivity, but also with respect to CH_4 emission.
For a precise evaluation of the effects of feed organic matter on CH_4, an analysis is required of all carbohydrates degraded in the rumen (sugars, starch, fibre), of protein degraded in the rumen, and of fat non degraded in the rumen. Evaluation of the effect on CH_4 per unit animal product requires an analysis of 1) the amounts of these substrates degraded in the rumen and leading to CH_4 production, 2) the amounts bypassing the rumen (including microbial matter) and becoming digested in the small intestine, and 3) substrates becoming degraded in the large intestine leading to an additional 10% of CH_4 (Bannink *et al*., 2011).

Cover slurry stores

Installing covers on slurry stores and covering manure heaps may decrease CO_2 and CH_4 emissions (Berg *et al*., 2006). Since NH_3 emissions will also greatly decrease, an increase in N_2O emissions can be expected at manure application. However, since the overall N use efficiency increases, covering could also lead to less manufactured fertiliser N inputs. The effect of a natural crust is similar but somewhat smaller. Covering of slurry stores also leads to fewer odours.

Manure treatment (manure acidification, anaerobic digestion)

There is a wide range of liquid manure treatment processes available such as anaerobic digestion with capture of biogas, physical and chemical separation technologies, and acidification. These technologies not only lead to energy production and/or more effective nutrient management, but they also reduce the biodegradation of slurry organic matter. Thereby they reduce the potential for GHG

emissions during subsequent storage and field application, whereas any solid fractions must be handled to prevent composting (e.g. Wulf *et al.*, 2002; Clemens *et al.*, 2006; Amon *et al.*, 2006a; Amon *et al.*, 2006b).
Anaerobic digestion of liquid manure is one of the most promising practices for mitigating CH_4 emissions from manure. When correctly operated, anaerobic digesters are also a source of renewable energy in the form of biogas, which is 60 to 80 percent CH_4, depending on the substrate and operational conditions (Gerber *et al*., 2013).
An important prerequisite of any manure treatment option is its applicability in the whole farm plan. Manure treatment must be aligned within the fertilisation plan of the farm. If not, the effect will be negligible or contra-productive.

Reducing age at first calving
As a result of reducing age at first calving, CH_4 emission per unit of milk or meat produced decreases. This results in an early economic return on investment and enhanced profitability, more rapid introduction of improved genetics into the herd and more pregnancies during the animals' productive life. However, primary factors limiting this approach are the liability to meet the nutritional needs of growth and gestation during the first parity and management skills of farm personnel (Hristov *et al*., 2013). As a result of a reduced age at first calving in dairy production, first lactation receives less energy, which is primarily dedicated to growth. Therefore, an impact on milk production is to be considered. With Holstein cows, on the contrary, the impact on meat production is very limited since the late stages of growth usually lead to additional fat and limited muscle (Faverdin, pers. com.). A prerequisite for reducing age at first calving is also that animals remain robust. The adoption of this option can be limited in systems were inseminations are not systematically synchronised.

5. Concluding remarks

This paper identifies relevant adaptation and mitigation options for specified systems in specified regions and discusses the synergies and trade-offs between these adaptation and mitigation options for those regions. Firstly, it provides a table with relevant adaptation and mitigation options for specified systems in specified regions as identified by local experts. Secondly, it discusses these adaptation and mitigation options. The options are both at the field/animal/farm scale and at the regional scale. Next to the identified options, there are also additional supporting options at the regional scale, such as use of regional climate forecasts. They can help target specific options like irrigation or feed storage. Systematic use of climate information could lead to better planning and decision making and reduce vulnerability to climate variability. Climate-informed policy and market-based interventions will reduce risk to vulnerable rural populations.

When the effect of options is explored or modelled at the regional scale, not only the technical potential of options should be taken into account, but also the economic impact and the behavioural and institutional barriers to implementation, since successful introduction of options is often hampered by region-specific economic and institutional constraints. The local experts have chosen the options by technical potential for adaptation and mitigation. They did not take the additional steps for actual implementation into account. However, since the options in this document are identified by local experts who are aware of constraints in their particular region, they are promising for the regional scale and can be used in designing mitigation and adaptation packages for Europe, Africa and South America. Packages should consist of adaptation/mitigation combinations suited to the levels of vulnerability and mitigation potentials in the different regions/systems. Table 1 provides the input for such packages for the differentiated regions.

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