Trends and challenges for sustainable development of sheep and goat systems

Arsenos G., Vouraki S., Ragkos A., Theodoridis A.

in

Capone R. (ed.), Bottalico F. (ed.), El Bilali H. (ed.), Ottomano Palmisano G. (ed.), Cardone G. (ed.), Acquafredda A. (ed.)
Pastoralism and sustainable development: proceedings

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens ;n. 126

2021
pages 13-33

Trends and challenges for sustainable development of sheep and goat systems

Georgios Arsenos[1], Sotiria Vouraki[1], Athanasios Ragkos[2], Alexandros Theodoridis[1]

[1]School of Veterinary Medicine, Aristotle University of Thessaloniki, 54124 Thessaloniki (Greece)
[2]Agricultural Economics Research Institute, Hellenic Agriculture Organization "Demeter", 11528 Athens (Greece)

Abstract. Sheep and goat farming systems in Europe are essential part of the agricultural industry providing ecosystem services to society. The sector faces many and diverse challenges. The main problem is low income despite heavy reliance on subsidies of Common Agricultural Policy (CAP). The notion is that subsidies under CAP will be directed at public goods (GHG, Biodiversity, animal welfare and rural livelihoods). Poor uptake of innovations and lack of new entrants are also obstacles for progress in the industry. Our objective is to give an overview of present challenges, trends and opportunities of the sheep and goat industry. A new paradigm for the future is proposed based on key findings of the project "Innovation for Sustainable Sheep and Goat Production in Europe; iSAGE". iSAGE, assessed the sustainability of the sector to future challenge such as climate change, food security, resource use efficiency and rural deprivation in marginal regions. The results showed that emphasis should be given to (i) supporting supply chains and increasing consumption of sheep and goat products through novel labelling, packaging and cuts, (ii) address climate change and greenhouse gas emissions using novel methodologies and technologies, and informing relevant policies particularly in pastoral systems, (iii) breeding for enhanced animal resilience, efficiency and adaptability, and promoting region-specific use of local breeds, and (iv) adoption of relevant innovations.
Keywords. Sheep – Goats – Challenges – Trends – Opportunities.

Titre. Tendances et défis pour le développement durable des systèmes ovins et caprins
Résumé. *Les systèmes d'élevage ovin et caprin en Europe sont des éléments essentiels de l'industrie agricole fournissant des services écosystémiques à la société. Le secteur envisage des défis nombreux et variés. Le problème principal est la faiblesse des revenus malgré une forte dépendance sur des subventions de la politique agricole commune (PAC), tandis que les subventions de la PAC seront dirigées vers les biens publics (GES, biodiversité, bien-être animal et développement rurale). La faible adoption des innovations et le manque de nouveaux entrants sont également des obstacles au progrès du secteur. Notre objectif est de donner un aperçu des défis actuels, des tendances et des opportunités des secteurs ovin et caprin. Un nouveau paradigme pour l'avenir est proposé sur la base des principales conclusions du projet « Innovation pour une production ovine et caprine durable en Europe ; iSAGE». iSAGE, a évalué la durabilité du secteur face aux défis futurs tels que le changement climatique, la sécurité alimentaire, l'efficacité de l'utilisation des ressources et le développement rural dans les régions marginales. Les résultats ont montré que l'accent devrait être mis sur (i) le soutien des chaînes d'approvisionnement et l'augmentation de la consommation de produits ovins et caprins grâce à de nouveaux étiquetages, emballages et découpes, (ii) la lutte contre le changement climatique et les émissions de GES en utilisant de nouvelles méthodologies et technologies, et en informant les politiques en particulier dans les systèmes pastoraux, (iii) l'élevage pour améliorer la résilience, l'efficacité et l'adaptabilité des animaux, et la promotion de l'utilisation des races locales, et (iv) l'adoption d'innovations pertinentes.*
Mots-clés. *Ovins – Caprins – Défis – Tendances – Opportunités*

I - Status of the sheep and goat sector

The European Union's (EU including UK before Brexit) sheep and goat population numbers approximately 98 million heads (86 million sheep and 13 million goats). The largest numbers of sheep are found in the United Kingdom (UK), Spain and Greece (27%, 19% and 10% of the EU total population, respectively), while Greece and Spain together hold more than 50% of the EU

total goat population (32% and 22%, respectively, European Parliament, 2017). In these countries, sheep and goats are often reared in marginal and socioeconomically vulnerable areas, where they are an essential part of the agro-ecosystems and have a special role in the provision of ecosystem services to society (Rodriguez-Ortega *et al*., 2014). These can range from the provision of food (meat and cheese) and wool to the 'non-marketed' services such as the regulation of climate systems (e.g. flood prevention, water purification) and the support of local cultural heritage.

Sheep and goats are reared on approximately 850,000 and 450,000 EU farms (including UK before Brexit), respectively. This corresponds to 113 sheep and 26 goats per farm. However, these numbers vary significantly across the EU with UK being first for sheep farms and Greece for goat farms. In terms of density of sheep per square kilometre, the UK ranks first, followed by Greece and Cyprus. Approximately 1.5 million people work in sheep and goat farms (European Parliament, 2017; 2018a).

The main product of the sheep and goat sector is meat. However, milk, cheese, wool and skin products are also of economic importance in many countries. Several such products have quality labels such as Protected Designation of Origin (PDO), which further enhances their economic potential. Amongst EU Member States, sheep meat production is especially important in UK and Ireland, whereas goat meat production in Greece. Sheep and goat milk is mainly produced in Greece, Spain, France, Romania and Italy and is mostly used for cheese-making (European Parliament, 2018a). Specifically, most sheep milk is processed by dairy industries into traditional cheese types some of which are PDO (e.g. Pecorino, Manchego, and Roquefort). Goat milk is often processed on farm into different local dairy products, including yogurt, and is mainly addressed to local or national markets. Nevertheless, there are also PDO goat cheeses produced by dairy industries (e.g. Murcia al Vino) and pasteurized goat milk for direct human consumption (Pulina *et al*., 2018).

However, small ruminants constitute just a small share of the total EU livestock output in terms of production and added value. According to recent statistics (European Parliament 2018a), in 2017, sheep and goat meat production accounted for almost 755,000 tonnes with a value of 5.8 billion euros (2% of total EU production and less than 6% of its value). Likewise, sheep and goat milk accounts for a minor part of the total agricultural output. In France, it ranges from 1% for sheep milk and 2 % for goat milk so, around 3 % for small ruminants. In Italy and Spain it ranges from a minimum of 0.9% to a maximum of 1.8%, while in Greece, sheep and goat milk contributes approximately 9% (Pulina *et al*., 2018). In the recent years, consumption of meat has decreased, whereas consumption of goat milk and cheese has increased significantly in several Member States. Furthermore, the EU is not self-sufficient in terms of sheep and goat meat; the main importing countries are New Zealand (>80% of EU imports) and Australia (11%). Finally, EU's exports are limited consisting mainly of live animals from Romania and Spain (European Parliament, 2018). Moreover, sheep and goat farming in Europe is characterised by great diversity in terms of production aims, farm size, breeds kept, levels of intensification, and socioeconomic and environmental attributes resulting in several different farm types (Girard *et al*., 2001). The H2020 project iSAGE (Innovation for Sustainable Sheep and Goat Production in Europe) developed a new common typology for sheep and goat production systems in Europe, which can serve as a useful tool to propose better targeted policy measures and strategies (Theodoridis *et al*., 2019). Specifically, through a meta-analysis of a literature review of the typological surveys in Europe and on data collected though an online survey of the iSAGE industry partners, an initial tentative 'broad typology' with 13 sheep farm types and 5 goat farm types was developed.

o Description of sheep production systems

(i) Farms with sheep keep confined and great dependence on purchased feed

(ii) Farms with confined kept sheep and provision of home-grown feed

(iii) Semi-extensive dairy farms

(iv) Dual purpose farms

(v) Traditionally managed farms

(vi) Low input meat farms

(vii) Medium input meat farms

(viii) High input meat farms

(ix) Cheese producing farms

(x) Pluriactive farms

(xi) PDO/PGI specialist farms

(xii) Organic/eco farms

(xiii) Intensive organic/eco farms

- **Description of goat production systems**

(i) Traditional meat production farms

(ii) Pastoral dual-purpose farms

(iii) Pastoral dairy farms

(iv) Confined dairy farms

(v) Cheese making farms

- **Final typology of sheep and goat systems**

The above farm types are not discrete and mutually exclusive to all countries. Therefore, this 'Broad' typology was further elaborated with the participation of research and industry organizations from several countries resulting in a final typology which best describes the current multiple sheep and goat systems in Europe**.** This typology consists of nine farm types in total (five for sheep farms and four for goat farms):

(i) Intensive dairy sheep and goat farms (e.g. high input of purchased feedstuffs)

(ii) Semi-intensive or semi-extensive dairy sheep and goat farms (e.g. normally pasture fed animals)

(iii) Intensive meat sheep farms (e.g. high input of purchased feedstuffs)

(iv) Semi-intensive or semi-extensive meat sheep and goat farms (e.g. normally pasture fed animals)

(v) Dual-purpose sheep and goat farms (farms where the farmer sees value in two or more different products such as meat and wool or meat and dairy).

II - Challenges of the sheep and goat sector

The European sheep and goat industry faces great challenges, which must be properly addressed to avoid further marginalization of the sector in the European Agrifood economy (Bernués *et al*., 2011; Dubeuf and Sayadi, 2014). Before finding strategies to counteract these challenges, their diversity needs to be characterised to understand which are the most relevant ones and easy to change. Additionally, the stakeholders responsible for driving this change also

need to be identified to develop robust strategies to reverse the effects of the most important challenges. The iSAGE project contributed to making the European sheep and goat sectors more sustainable, competitive and resilient. Part of the project activities was to identify and quantify the importance of the current and future challenges that may compromise the sustainability of the sheep and goat industry in Europe. To identify and quantify these challenges, iSAGE used a participative multi-stakeholder approach with industry and research institutions working together. Extended literature reviews, descriptions of the sheep and goat sector in each involved country and semi-structured interviews with farmers revealed plenty of technical/social, market, policy/financial and environmental challenges.

2.1 Technical/social challenges

One of the most important issues faced by the sheep and goat industry is the lack of professionalization of farmers and limited management training especially in meat sheep and goats in extensive and semi-extensive systems. Most sheep and goat farmers do not follow an established methodology regarding the management of their enterprises. The latter frequently leads to farms, which operate inefficiently and with reduced productivity and profitability. Sustainability assessments at a Global, Mediterranean and Northern European level have clearly shown that such farms rely on public subsidies to remain economically sustainable (Dýrmundsson *et al*., 2006; Bateman and Balmford, 2018; Guth *et al*. 2020).

The ageing farming labour force, together with the lack of intergenerational transfer of farms, is another problem facing the sheep and goat sector in Europe. Sheep and goat farmers are older than farmers in other sectors, sometime reluctant to make changes, and young people are not interested in the business. There are many reasons that could explain the decision to accept or not the intergenerational transfer in sheep or goat farms, amongst those young farm family members' social profiles and discourses. Moreover, rural populations are declining whilst farms are expanding. Therefore, labour is getting harder to find. At the same time, sheep and goat farming is very labour-intensive and requires specific skills. The sector is being hampered by a lack of technical services and training, which results in varied levels of productivity.

At the same time, the sector is characterised by a low level of innovation and limited investments in technology (Dubeuf *et al*., 2014). The improvement of farm technology, as well as boosting innovations in farm practices, process and products is considered one of the main strategic priorities for the sheep and goat sector, particularly at the farm level. Relative to other agricultural sectors, technology and innovation in sheep and goats has remained relatively stagnant and neglected by both the supply chain actors and mainstream research (Martin-Collado *et al*., 2017). This is especially true for the goat sector. Goat production systems range from traditional systems, with flocks of meat or dual-purpose (meat and milk) animals, to more specialised systems in dairy production. Family businesses are the norm and hired labour is rare.

This may explain why livestock newly developed technology is still not being adopted in the goat sector. Moreover, in terms of farm management, there is notable shortage of suitable tools that would facilitate sheep and goat farmers to make management planning decisions based on the analysis of relevant data and information and to apply well proven methods for production optimization and profits maximisation (Häni *et al*., 2003; The Cool Farm Tool, 2015, Meul *et al*., 2008; Gerrard *et al*., 2012; Villalba *et al*., 2019).

The sheep and goat sector is very fragmented and the main characteristics vary by EU Member State, or even production area; species (sheep, goat, combined), type of farming (milk, meat), systems (suckler or suckler-fattener / intensive or extensive), types of products (heavy lambs, light lambs), structures (small or large), importance of the activity within the area (from very important to marginal) (Ares(2011)1350301 - 13/12/2011). Moreover, production models in Mediterranean countries are highly more fragmented than those in Central Europe. The iSAGE

surveys indicated that this fragmentation may be more of a threat for the dairy sector, probably in relation to the complexity of the market, as compared to the meat sector.

Finally, the lack of integration/cooperation, farmers' gender imbalance, and societal awareness of farmers' role, the low competitiveness of the sector and the fact that researchers do not address relevant issues pose additional challenges of the sector.

2.2 Market challenges

A major challenge is the fact that incomes for sheep and goat farmers are among the lowest in the agricultural industry, with inadequate farm-gate prices and poor monetisation of by-products, and depend heavily on public support over a long period (Dýrmundsson *et al*., 2006; Dubeuf *et al*., 2014; European Parliament, 2018; Bateman and Balmford, 2018; Guth *et al*. 2020). This lower income is the reason that sheep and goat farmers were among the first to receive direct subsidies from the Common Agricultural Policy (CAP) to compensate for financial falls (Milàn *et al*., 2003). Direct subsidies often represent most of the net farm income of sheep and goat farms, and this is particularly true for those farms located in less favoured areas (Dýrmundsson, 2006; Guth *et al*. 2020). Moreover, production costs are continuously increasing; primarily for feedstuffs; secondarily for fuel, labour and animal health (European Parliament, 2008). At the same time, electronic identification constitutes an additional cost, which is perceived to be too high in the current situation. By comparing the break-even points and sheep milk prices previously reported, it seems that most dairy sheep farms in France and Greece are working under the profitability threshold, whereas in Italy price is aligned with the cost, on average, but with large fluctuations among years and high variability among farms (Pulina *et al*., 2018). Moreover, sustainability assessments within the iSAGE project showed that extensive sheep farms generally achieve lower values within an approximate net profit calculation than intensive farms and as expected organic farms are more reliant on subsidies than low input farms.

Moreover, the sector is characterised by low consumer demand. Specifically, the consumption of lamb in Europe, particularly in northern Europe, is beset by a poor public image, low value for money and poor consumer knowledge and education on consuming local products. The relatively high fat content and the time required to cook are also reported to hamper market penetration. Moreover, sheep meat has a taste that is not to everyone's liking (Mandolesi *et al*., 2020). In particular, the consumption of lamb by young consumers is decreasing. Products such as leg of lamb or stewing lamb have no appeal to single people or young couples, as they are often family- sized portions and cuts that are complicated to prepare or need to be cooked for a long time. It is interesting to note that when new products are introduced to the market that are specially aimed at young consumers, such as minced lamb meat in the United Kingdom or émincé of lamb in Ireland, sales increase rapidly. This suggests that low consumer demand can be addressed by offering new products. Although in a lesser extent, barriers also exist for the market penetration of sheep and goat cheese. Specifically, surveys showed that the high price of sheep and goat cheese (higher than bovine) as well as the poor knowledge and awareness of consumers on the production system (how sheep and goats are raised for the production of milk) and what type of milk (sheep, goat or cow) is used for cheese-making limit their demand. Moreover, the fact that many consumers are prejudiced against the taste of sheep and goat cheese and that they consider it as fatty are also limiting factors.

Finally, the EU sheep and goat sector also faces a volatility of commodity (milk and meat) prices and an increased import from non-EU countries. Such difficulties as well as the unfair trade and the market's control by few companies have contributed to a decrease in livestock numbers in the last decade and to many farmers becoming discouraged and leaving the sector. For example, Italy is losing market share of Pecorino Romano cheese because of politics and the fact that it has only one main importer (the United States) with consequent problems related to low milk prices and competitiveness of sheep farms (Pulina *et al*., 2018).

2.3 Policy/financial challenges

Sheep and goat farmers depend heavily on subsidies to remain financially sustainable. Subsidies, provided by the European CAP, have decreased both production in economically less viable areas and the competitiveness of the sector (ANT International, 2011; Guth *et al.* 2020). A considerable number of sheep and goat farms, taking advantage of previous per-head sheep and goat subsidy schemes, have been modelled to aggressively maximize flock size without accounting for the negative consequences in business and ecological sustainability (overgrazing, land erosion, financial inability to sustain the flock on purchased feedstuffs, environmental footprint etc.). However, in France, the PDO rules (limitation of purchased feed) have limited efforts to improve the flock size. Such schemes have already been phased out and replaced by grants paid to farmers who own land rights, while soon environmental performance will also be taken into account (European Parliament 2019). The above operational model, although viable in the past, cannot guarantee any longer the survival of the sheep and goat sector. Finally, issues relating to recognition and valuation of public services and EU policy measures forced with no scientific evidence further tackle the sustainability of the small ruminant sector. The role of research is important to produce rational arguments on which the choice of orientations and strategies can be based.

2.4 Environmental challenges

The climate in Europe is changing, with higher temperatures, and more variable volume and annual distribution of precipitation (Kovats *et al.*, 2014). These changes are influencing, sometimes dramatically, other abiotic variables including higher likelihood and intensity of fires and floods and changes in nutrient cycles and wind speeds. Such changes inevitably impact on small ruminant farming – both on animal performance directly and the production system more widely. As with all agriculture, small ruminants are affected by the wider environment, whether through direct effects of climate on animals, or indirect effects via pasture, forage, feed crops or parasites and pathogens. Impacts will be very unequal amongst different bio-climatic regions, countries and small ruminants' production systems; Southern European countries are expected to suffer the most from these changes in climate both for pastures productivity and grass quality (Dellar *et al.*, 2018) and, at the animal level. At the same time, the sheep and goat sector, as it has been done for other ruminant systems (e.g. cattle), has been implicated for contributing to climate change mainly through their large share of global methane emissions. Both of these aspects represent a challenge for the future of the sector; it should be noted however, that the large potential of their soils to act as carbon stores though pasture management and the important functions of the sheep and goat farming systems is neglected when comparing emissions of GHG among different livestock systems.

The low rate of adaptation of high productive breeds to new environments combined with the lack of well-established breeding programmes for local breeds in most areas is also a major problem. Local breeds are usually small in population size. More numerous breeds have a greater opportunity to increase selection response, because a larger number of individuals allows for greater selection differential, especially when artificial insemination and other reproductive biotechnologies are used to increase the number of offspring per individual. Breeding companies also have more interest in larger imported breeds because the potential market is greater and because the truly superior animals are more extreme and thus more valuable (Biscarini *et al.*, 2015).

Moreover, the increasing number of attacks on sheep flocks and goat herds by predators (wolves, bears and lynxes) poses a further challenge for the sector; conflicts with wildlife are becoming costly for small ruminant farmers. Such incidents have been attributed to the proliferation of these animals as a result of the protection measures enshrined in the directive on the conservation of natural habitats and of wild fauna and flora.

Other environmental challenges involve limited land access, lack of integration of agriculture with livestock and the possibility of future environmental policies limiting intensification and reducing grazing levels to a point where sheep farming becomes impractical and habitat degeneration occurs, risking environmentally damaging wildfires in periods of dry weather.

2.5 Relevance of challenges and easiness to address – which are the top priorities?

The high heterogeneity in the small ruminant production systems across Europe results in a variability to the perception of relevance of the challenges faced by the sector. Based on the expert group's surveys in the iSAGE project, geographical region (e.g. Southern vs Central Europe) is one of the main drivers that determine the relevance and difficulties to address the main challenges of the small ruminant sector. In southern countries, technical/social and environmental challenges are more relevant than those from central countries, except for increasing sanitary issues, youth involvement and wildlife conflicts. The type of product (meat vs dairy) and level of intensification can also modulate the relevance of these challenges. In general, the extensive farming systems are perceived as more vulnerable to several challenges such as low competitiveness, low female involvement, increasing sanitary issues, low consumer demand, lack of traceability, climate change threats, wildlife conflicts or limited access to land. Moreover, the relevance of these challenges progressively decreases for semi-extensive and intensive systems suggesting that the intensification can help to tackle some of the abovementioned challenges. On the other hand, the type of livestock species (sheep vs goats) is much less relevant.

However, using the priority index as an indicator of the relevance and easiness to address, the 10 most important challenges to face in all cases are:

(i) Low consumer education in product – external threat

(ii) Low promotion of local breeds – internal weakness

(iii) Low consumer knowledge about farming – external threat

(iv) Poor business management training – internal weakness

(v) Researchers do not address real problems – external threat

(vi) Unfair trade, lack of traceability – external threat

(vii) Low professionalization – internal weakness

(viii) Slow adoption of innovation – internal weakness

(ix) Low adaptability of high producing breeds – internal weakness

(x) Poor recognition of public services – external threat

Amongst these challenges, half of them are internal weakness, meaning that they need more action from the sector itself (farmers and associations), while external threats require a strong involvement of Governments in order to be properly addressed.

Based on the above and with the help of iSAGE partners, the top priorities for dealing with the above challenges were identified for Finland, France, Greece, Italy, Spain, Turkey and the UK (Table 1). All countries identify better market access (such as export opportunities, understanding of public preferences and how to increase consumer awareness, development of niche markets, localised production and local supply chains) and efficient breeding programmes focused on functional traits, genomic selection and local breeds as strategic priorities for the development of the sector. Meanwhile, innovative production practices and improved human

capital in rural areas were reported as priorities by six countries. Mentioned only twice were the priorities concerning environmental sustainability and improvement of the structural characteristics of the sector.

Table 1. Strategic priorities per country

Development axes	Finland	France	Greece	Italy	Spain	Turkey	UK	Total
Innovation in farming practices - Productivity		X	X	X	X	X	X	6
Improvement of human and social capital		X	X	X	X	X	X	6
Environmental sustainability					X		X	2
Market access and economic performance	X	X	X	X	X	X	X	7
Product quality, hygiene and food safety		X	X	X	X	X		5
Genetic improvement	X	X	X	X	X	X	X	7
System structure and exogenous factors			X	X				2
Total	2	5	6	6	6	5	5	35

III - Trends and opportunities

In the light of the challenges faced by the sector, the prevailing view is that only farms which take up innovative solutions to modernise and rationalise their modus operandi with an emphasis on flock size, management of feeding and grazing residues as well as marketing strategies are likely to remain in business (Bernués *et al*., 2011; Paraskevopoulou *et al*., 2020). In this regard, current technological trends such as digital technologies, Internet of Things, decision support tools, and machine learning are opportunities that could be used to re-design the sheep and goat sector towards remaining sustainable.

Furthermore, the severe decrease in consumption of sheep and goat meat within the EU the last 15 years has led the European Commission, following the recommendations of the Sheep meat Forum, to support promotion initiatives in the EU and third countries co-financed by the EU. Specifically, EU funding is directed to campaigns focused on increasing sheep and goat meat consumption with emphasis on traditional products, but also towards introducing newer cuts with respect to consumer choices. Moreover, opportunities arise with current trends in the supply of dairy products and in kid meat exports to third countries. Given these opportunities a greater effort should be paid for competing with the main exporting countries. Moreover, New Zealand's transition from frozen exported meat to fresh or chilled meat must be taken into account in future negotiations for a free-trade agreement (European Parliament, 2018a; 2018b). The latter remains unclear considering the impact of Brexit and its negotiations on the import/export of lamb meat with the UK (and the impact that this could have on NZ qiuotas).

At the same time, promising trends are also identified for the dairy sheep and goat industry across Europe. Specifically, in Italy, the dairy sheep and goat sectors are pushed by processing industries towards increasing the amount of milk destined for the international market. In Spain, the level of dairy specialization and the size of sheep and goat farms have increased with the increase in milk yield per animal and total milk production of the intensive farms, pushed by favourable milk prices. Finally, France is improving the efficiency of dairy sheep and goat farms by increasing milk yield per animal, thus maintaining the share of French cheese in the international market (Pulina *et al*., 2018).

Although local breeds have been less frequently used in intensive systems and preserved in situ in marginal territories, the situation is changing in the last decades in Europe, as some local

traditional breeds have developed breeding programs to increase their productivity, and in some areas 'compete' with high-yielding dairy breeds (e.g., the Saanen and Toggenburg) and perform better than local stocks that are often crossed (Biscarini *et al*., 2015). Some local breeds already have sufficiently high production to achieve profitability, but low performance regarding functional traits. Other breeds may obtain greater benefits by improving output while maintaining their characteristic secondary traits, such as adaptation to the environment.

Promising for the future of the sheep and goat sector is also the fact that emphasis is being given in supporting young farmers through an increase in direct payment schemes. Moreover, sheep farming still provides an achievable access to farming for young people that may not own land or have high levels of capital (European Parliament, 2018b). On the other hand, trends relating to climate change raise concern and should be considered. Specifically, a detailed review and meta- analysis undertaken within the iSAGE project reveals that across the whole of Europe, rainfall is becoming more sporadic and heavy rain events may increase substantially in most areas and seasons (Jacob *et al*., 2014; Kovats *et al*., 2014; Madsen *et al*., 2014). Dry spells will also become longer (although less frequent) in Central regions and especially in Southern Europe, where more frequent and longer droughts are additionally expected (Forzieri *et al*., 2013; Jacob *et al*., 2014). Temperature is also expected to increase. Warming is expected to be greatest in the Northern and Alpine regions by 2.0–4.2°C and 1.9–3.4°C respectively but will likely reach a minimum of 1.4°C everywhere (Jacob *et al*., 2014). Temperature increases may drive an increased incidence of heat stress in sheep and goats (Al-Dawood, 2017). Heat stress has numerous consequences for animals, such as impaired productivity (Lu, 1989; Marai *et al*., 2007; Al-Dawood, 2017, and references therein) and reproductive performance (Sawyer, 1979) and increased disease risk. In general, goats tend to tolerate heat better than sheep, and are less susceptible to environmental stress than other domesticated ruminant species. However, iSAGE results indicate opportunities for selectively breeding for enhanced adaptability to climate change and efficiency. Moreover, the modelling approaches used within iSAGE suggest that most regions, except for Southern Europe, are likely to see grassland yields either increase or stay the same, which is either good or neutral for grazing livestock.

Finally, it should be noted that the European Commission is working towards tackling climate change and environmental-related challenges. Additionally, to existing environmental policies, new medium and long-term (e.g. for 2050) policies and strategies are currently being discussed as part of countries commitments to the Climate Change Paris Agreement (Forsel *et al*., 2016). The notion is to achieve the long-term goal of holding the increase in average global temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. These targets have been included in the new European Green Deal Communication (European Commission, 2019a). Given that food systems are currently considered responsible for almost one third of GHG, with the European Green Deal, all actors across the food chain will need to adjust to new EU standards under the "Farm to Fork" strategy. Special emphasis is given to European farmers with the Commission's proposals for the common agricultural policy for 2021 to 2027 stipulating that at least 40% of the CAP's overall budget would contribute to climate action. Farmers will be rewarded for improved environmental and climate performance such as improved nutrient management to improve water quality and reduce emissions. Moreover, strategic plans involve organic farming, agro-ecology, responsible medicine use, benchmarking and understanding productivity gains and stricter animal welfare standards (European Commission, 2019b). However, such measures require profound transformations on how farms are currently being managed and raise an issue of possible unfair competition and negotiating trade agreements with third countries.

IV - A new paradigm of the sheep and goat industry

The iSAGE project aims at helping the European sheep and goat industry to become more sustainable, competitive and resilient. Based on the major challenges identified, the top priorities and the current trends, using a multi-stakeholder approach, iSAGE provides best practices and recommendations for facing these challenges and sets a new paradigm for the future of the sheep and goat industry.

4.1 Supporting products and supply chains

Detailed interviews with consumers and retailers revealed that organic labels, national origin and PDO drive consumer willingness to pay more for sheep and goat products. Specifically, the main attributes consumers ask about when buying lamb meat are fat content, preparation, provenance, traceability and quality control, which tend to be associated with health and food safety. Therefore, possible ways to boost purchases of sheep and goat meat in the future include (i) increased provenance labelling and assurance schemes, (ii) providing easy to cook and novel lamb meat cuts, (iii) 'tell the whole story' from the breed, and (iv) the availability of novel recipes (Mandolesi et al., 2020). Regarding dairy products, special emphasis should be given on cheese for which the main strengths identified are the perceived health benefits, the wide assortment and the fact that it is considered by consumers as something novel. The main recommendations for cheese include (i) branded products such as PDO Protected Geographical Indication (PGI) plus renowned brand name, (ii) convenient formats such as single-portion and fixed-weight product packaging, (iii) organic plus fair trade, which targets a specific consumer segment, and is somewhat novel for dairy products, and (iv) clear label cues or claims such as a national flag on the packaging, 'easy to digest' claim, punchy and targeted messages to describe different cheese characteristics.

However, in order to support and boost the performance of the whole sheep and goat supply chain a more holistic approach is required. Specifically, for the **meat supply chain** the following recommendations are drawn:

- A mixed approach based on selling through different routes and product innovation is recommended in order to handle carcass imbalance and improve supply chain resilience in a volatile market context for lamb meat.
- Local firms can establish dedicated lamb meat supplies where supply chain alignment is possible (only) to some extent through the adoption of some practices of the lean and agile philosophies.
- Product innovation, flexibility and real-time adjustments can contribute to a better lamb meat supply chain alignment.
- Working relationships between downstream and upstream supply chain members are recommended to identify quality specification of lamb, to develop and market a range of products (including new meat cuts) that optimise the use of that specification and reduce waste.
- Less specialised lamb meat supply chains which engage in valorisation of by-products and waste or breeding dual purpose sheep (meat and wool) can secure sustainable returns in contexts where the added value is distributed along the supply chain.

Moreover, for the **dairy supply chain** the following recommendations are drawn:

- Setting trading conditions relating to milk price, volumes and quality requirements before the milking season, is necessary to guarantee sustainability of the production

base and innovation potential for the sector. Collective negotiations and written contracts are to be preferred.

- Competitiveness through cost leadership must be pursued by improving efficiency at supply chain level rather than cutting milk farm-gate price.
- Logistics efficiency is strategic in cost leadership and can be improved by planning the collection and delivery of milk with suppliers and by exploiting economies of scale, such as absorbing milk supply from additional farmers and managing collection costs.
- Less specialised goat supply chains, such as dual-purpose breeds producing milk and meat (in countries where this is not problematical) can secure sustainable returns.
- Product and market innovation have to be strategically implemented with the involvement of all supply chain members, including producers for the milk quality requirements and retailers to gain premium shelf space.

4.2 Coping with climate change and reducing GHG emissions

Climate change adaptation and mitigation measures need to be tailored to specific conditions (e.g. climatic area, production system, etc.). Feed management is a general area where climate strategies apply to the wide diversity of systems and contexts. For example, the use of alternative feeds is especially relevant in a global future scenario of insufficient and highly variable forage and cereals availability. Given that sheep and goats can transform nutrients from poor quality feed resources into high quality milk and meat, by-products from the agro-industry such as tomatoes and olive- by products could be an option. Such a strategy would improve resource use efficiency of the systems involved, promote a circular economy and decrease competition for human-edible feed resources (Eisler *et al.*, 2014). Moreover, increasing mixed, and multi species grass leys pastures is a good measure in order to adapt to potential shortages of global protein sources in Europe, or to face the expected decrease of protein content and digestibility of C3 grasses in non-leguminous plants under climate change conditions (Soussana *et al.*, 1995; Dumont *et al.* 2015). Also, growing legumes can cut emissions by up to 20% at farm level due to less need for synthetic fertilisers. Additionally, using forage mixtures farmers can optimise the balance between forage utilisation for animal performance and sustainability in terms of environmental impact and biodiversity.

Regarding extensive small ruminant systems, in rainy areas, manipulating forage quality and quantity through grazing management, fertilization and use of seeded forages is recommended. On the other hand, in drier areas, manipulation of the animal's physiological state and different mobility patterns will be more appropriate. However, it should be noted that reducing grazing from marginal land does not necessarily improve farm-GHG and N losses, or resilience (D3.1). Long-term adaptations can be developed through improved plant breeding. New forage resources are required that are adapted to high temperatures, drought, and increased CO_2. This might be achieved through exploitation of traits for dehydration tolerance and summer dormancy, either in novel species or for introducing traits into existing widely used grasses and legumes (Volaire *et al.*, 2009; Dumont *et al.* 2015). In terms of coping with animal heat stress, breeding for higher resistance to heat stress and general management strategies such as ventilation, adequate stocking density, shearing and optimal nutritional management are recommended.

Finally, climate policies directly affecting small ruminant production systems should use the most updated methodologies and emission factors, include different metrics and estimates of potential soil organic matter sequestration from grassland-based systems. In the last years, most GHG emissions calculations were based on methodologies of IPCC dating back to 2006 (IPCC, 2006). Calculations made in iSAGE using the updated IPCC report (IPCC, 2019) revealed that previous GHG emission estimates from small ruminant production systems have so far been overestimated (by 18% and 28% for sheep and goats in Europe, respectively).

Additionally, iSAGE calculations using the new GWP* metrics also revealed that the small ruminant production systems in Europe have not caused additional warming to the atmosphere in the last decades. Such findings should be considered by relevant environmental policies. Moreover, any climate strategy involving small ruminant livestock systems should consider separating methane (i.e. short-lived GHG) from long-lived GHG emissions such as CO_2 and N_2O.

4.3 Breeding for resilience and sustainability

Phenotypic, genetic and genomic analyses conducted within iSAGE revealed that animal traits associated with adaptation to climate, plasticity across environments, and sustainability and resilience to harsh environments are partially under genetic and genomic control and, thereby, amenable to improvement with selective breeding. Specifically, the proposed traits suitable for inclusion in breeding programmes are:

5 Climate adaptation: Rate of change in animal performance to changes in thermal load under heat or cold stress.

6 Sustainability traits: Health related indicators (faecal egg count, immune status), welfare (female longevity and progeny survival), feed intake, growth and meat quality and functional milk production (udder health, persistency of lactation).

7 Resilience to harsh environments: Body condition score and biomarkers of body reserve mobilization.

A set of genomic markers and candidate genes were identified, which could serve as a starting point to enhance the efficiency of genomic selection for adaptation to climate phenotypes, manifested by changes in milk, protein and fat yield, faecal egg count, growth, and immunological profile in response to weather volatility. iSAGE results revealed that local sheep and goat breeds are more suitable for the environment where they have evolved in comparison to newly introduced ones, although some of the latter seem to be better adapted to farming in specific geographical areas and climatic conditions. This calls for both locally contextualized analysis of the individual breeds and deeper study of the animal resilience traits for potential use in selective breeding programmes. However, based on the above and the different perception between different regions in Europe on the challenge of maximising the use of local breeds, it is recommended that any relevant upcoming policies are more contextualized for different regions than they have been before. Any effort to add value to local breeds is important, especially as a contribution to the prospects of their conservation through sustainable use.

4.4 Adopting innovations

Above all, the future of the sheep and goat sector lies on the adoption of new technologies and innovations as they can increase its competitiveness, resilience and sustainability and decrease reliance on public support.

- ***Technical and computational innovations for overall sustainability***

Currently, there are plenty of available technical and IT innovations that can deliver win-win effects on the overall sustainability of the small ruminant production systems. Examples of such innovations include:

1. iSAGE Public Good tool (PG tool)

The iSAGE Public Good tool (PG tool) highlights sustainability scores in sheep and goat farms. Specifically, it provides a picture of how the farm performs with respect to a selection of 13 spurs (areas) that collectively make up the sustainability equation; soil management, agri-

environmental management, landscape and heritage, water management, fertilizer management and nutrients, energy and carbon, food security, agricultural systems diversity, social capital, farm business resilience, animal health management, animal welfare management and governance. The results are presented in a non-confrontational manner, depicted in a radar diagram that is simple to interpret and provides a perfect catalyst for discussion (Figure 1). In this regard, the PG tool can motivate farmers to review their farming activity considering other perspectives than purely economic ones (e.g. environmental impacts). The PG Tool assessment can be repeated; for example, to look at how a change impacts on the other areas of sustainability. Finally, an online toolbox, based on the indicators included in the PG tool is also available for farmers to easily assess the sustainability of their farms.

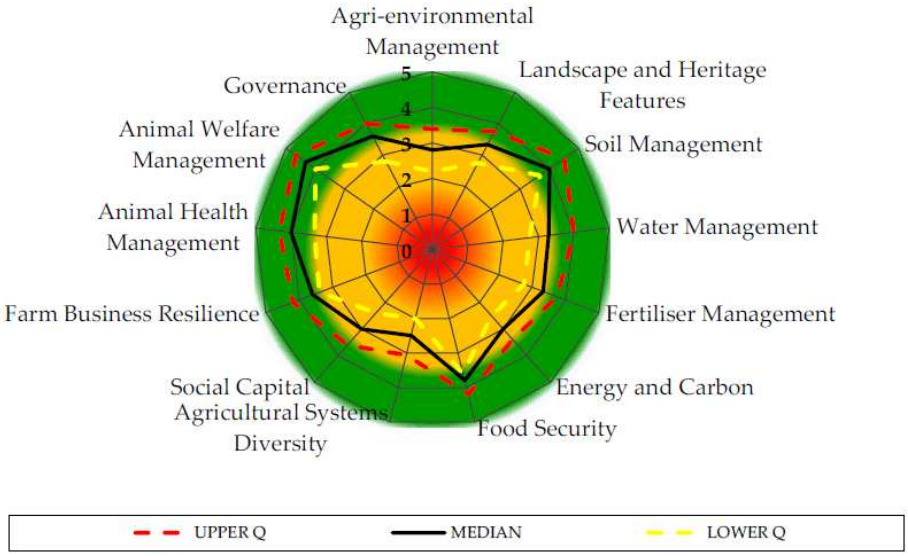

Figure 1. Results in a form of a radar diagram from the PG tool sustainability assessment. Upper, median and lower quartile values illustrate the strengths and weakness of the farm.

2. iSAGEDSS

The iSAGEDSS is a web-based, model-driven, decision support system for the efficient management of meat and dairy small ruminant farms (Vouraki *et al.*, 2020). This system allows sheep and goat farmers to make annual management planning decisions by testing future what-if scenarios. The users input data regarding all important farm parameters (flock size, production, feeding, grazing, income from subsidies and farm prices) and with the use of an energy and protein based algorithm they are provided with reports that are focused on profitability and productivity; the impact of management decisions is explicit. Farm income, variable costs and gross margin are estimated taking into account production estimates such as live weight and carcass weight of finishing lambs and milk production of lactating animals (according to the production system) based on their nutritional management. Moreover, the iSAGEDSS provides comprehensible charts of income and cost analyses as well as bar plots of feed costs and variable costs per animal category. This way, farmers may understand their cost structures in depth, identify which factors affect profitability and be incentivized to utilize additional sources of income. At the same time, pasture availability at the end of the year and stocking rate are estimated which help farmers towards testing more environmentally sustainable solutions. Overall, farmers benefit through tighter control over revenues and

expenses and ability to plan for increased productivity and profitability with similar or lower costs, elimination of dependence on public subsidies and ecological awareness.

3. Eskardillo

Eskardillo, a platform-based individual data collection tool, is successfully used in intensive dairy goat farms in Spain to help farmers make breeding, replacement, or culling decisions (Belanche *et al*., 2019). Specifically, Eskardillo is an Android smartphone-based terminal which incorporates various elements: (i) an electronic chip reader to identify animals *in situ*, (ii) a barcode reader to identify tubes with biological samples (milk, blood) or drugs used, (iii) a digital camera to take pictures of post-mortem certificates, (iv) a keyboard for data input, (v) a Wi-Fi connection for data transfer, (vi) a mobile-phone SIM card to store data, (vii) a touchscreen to navigate through the different pages, and (viii) software for data interpretation. However, Eskardillo tool relies on three principles: (i) systematic on-farm individual data recording together with remote data acquisition as a result of the milk control, morphologic evaluation and genetic selection programme, (ii) data storage, processing and interpretation by a supercomputer placed at Cabrandalucía headquarters (Granada, Spain), and (iii) interactive feedback of processed data to the farmer to optimize farm management. The data-driven management decisions can be performed using either a laptop-based software or the Eskardillo smart-phone terminal.

4. Mobile Flock Management Software

The Mobile Flock Management Software is aimed at sheep farmers who need an easy to use 'point and click' solution to keep legislative records and build flock performance data. Metadata used in the software include ewe reproductive performance, overall productivity, lamb growing rate, survival rate of new-borns, and flock health status. The system detects alerts occurring in the farm and suggests for troubleshooting. This innovation combines cloud, IT technologies and farming practices, and explores technological opportunities to improve production efficiency in livestock farming. Therefore, it can be considered as an invaluable support for purchase, cull or breed decisions based on targets of flock performance.

- ***Breeding and genetics innovations***

Recent advances in animal breeding, molecular genetics and DNA analysis have boosted the development of new tools in breeding programmes. Among these tools is the inclusion of new functional traits in the breeding scheme (e.g. longevity, disease resistance, etc.), which until recently have focused only on production traits. The inclusion of longevity in sheep breeding goals was demonstrated within the iSAGE project using the example of Lleyn sheep in the UK. This new breeding goal will enable farmers to more readily identify the genetic potential of livestock for living longer in the flock and therefore, reduce the 'wastage' of animals through involuntary culling (e.g. culling due to disease or poor fertility). The new breeding goal will also improve economic sustainability and efficiency by avoiding the inadvertent use of animals from families with low life expectancy and reduced lifetime performance. Breeding for enhanced longevity has been considered successful so far, and will likely be extended to other sheep breeds, such as Dorset and Texel.

Despite the tested efficiency of breeding indexes in increasing sheep productivity and profitability as the New Zealand and Australia sheep industry experience shows, the use of indexes in many European countries is very limited. There is a huge space of improvement in this area which should be fostered by public institutions given the lack of interest showed by the industry.

Moreover, assessing parasitic resistance of UK local and newly introduced sheep breeds in organic/low input and conventional farms showed that saliva samples are easier to collect compared to faecal samples. It is hoped that, in the future, saliva sampling alone will be

adequate to select sheep for increased parasitic resistance provided that salivary IgA (a parasite-specific immunoglobulin) seems to be a good indicator of a parasite infection.

At the same time, the development of molecular genetic techniques has allowed the identification of major genes, which could have a large effect on the traits of interest and, therefore, their management could generate important benefits for the farmer community. For example, within iSAGE, the ROA allele was used as an innovation case study for improving prolificacy in Rasa Aragonesa breed in Spain. The presence of the ROA allele in the mother increases by 0.31 the average of lambs per birth. Moreover, the iSAGE modelling approaches revealed that this innovation results in large benefits at the economic level (mainly due to a positive balance between an increase in total feed costs and more lambs being raised for the same amount of ewes), but also at the environmental level (reduction over 10% of GHG emissions). Therefore, the search for these types of genes and subsequent integration in selective breeding should be supported by farmers, farmers' institutions and public agencies.

Finally, there is genomic breeding, which uses direct genomic information as additional information in breeding schemes. The use of genomic information would allow for a more efficient selection of breeding animals, among other things, by reducing the generation interval and by allowing the estimation of genetic merit with high precision. Until now, only France, Spain and the UK have included genomic information in breeding schemes.

- ***Reproduction technologies***

Reproduction technologies have evolved extensively in the last decades and multiple methodologies and innovations, such as artificial insemination (AI) and embryo transfer have been developed and are available for farmers to apply. Proper use of most of these technologies is important to maximize animal performance and farm profitability. Although there is still space for the development of reproductive technologies, the main issue in the sheep and goat sector is the uneven use of these technologies across farming systems, breeds, regions and countries. Therefore, although some of these technologies, for example AI and oestrus synchronization are routinely used in some breeds, they are an innovation in some other breeds or countries.

One of the most important reproduction technologies is AI because it maximizes the spread of genetic improvement to the whole population, but also because it allows for the progeny test, which can help to identify males with high genetic breeding values. The main problem of this technology in sheep and goats is that it leads to low fertility rates (30% to 60%) due to different causes such as the anatomical characteristics of the reproductive tract of these species. Moreover, the AI technique itself and the tools used in AI implementation at farm level may be another cause of its inefficiency. Therefore, all efforts to improve AI success may contribute to the sustainability and efficiency of the small ruminant production systems. In this regard, in iSAGE, a new speculum for AI in sheep and goats was tested to see whether it performs better than the classical duckbill and tubular AI instruments, in terms of increasing the fertility rate, but also in terms of labour ease or number of AI personnel needed. The main advantage of the new speculum was found in dairy breeds by allowing inseminations to be performed in the milking parlour without lifting ewes. This also led to the consequently reduction of ewe stress, ease of the labour burden, and the reduction of the number of personnel needed in the process. Meat breeds do not seem to benefit from this innovation, due to technical aspects that should be improved by adapting the instrument to the specific anatomical characteristics for each of them.

- ***Product and market innovations***

There is a great need to implement and support innovation at the product and market level. New packaging and cuts, development of quality labels or other certification and traceability systems and new marketing campaigns to make society aware of the environmental and social services of sheep and goat farming systems, are key strategies to produce significant benefits for the small ruminant sector in EU. Useful examples of innovations that were tested within the iSAGE

project include: (i) a Participatory Guarantee System for Brogna sheep Association in Lessinia, (ii) the food production from goat milk and lamb meat enriched in conjugated linoleic acid by feeding, and (iii) marketing innovations for transhumance dairy products.

5. Participatory Guarantee System (PGS) for Brogna sheep Association in Lessinia

The Participatory Guarantee System (PGS) for Brogna sheep Association in Lessinia, Italy is an alternative to the official PDO/PGI quality assurance system. While PDO/PGIs are more aimed to certify the origin of products, PGSs are more flexible and allow communicating the environmental and social benefits of extensive small ruminant farming systems. PGSs imply lower bureaucratic burdens and lower cost than PDO/PGI certification and are particularly suited to small farmers located in highlands and hinterlands. Although the short time since the establishment of PGSs is not enough to analyse the impact of such an innovation in the mid and long term, there are some initial signs that indicate a promising potential to improve marketing and, therefore, the demand of products associated to it. Regional authorities are showing a strong interest in the initiative, confirming public support through a measure for animal biodiversity direct support included in the Regional Rural Development Plan, which is paid to farmers rearing the Brogna breed, and also through other support measures in the short term, possibly including the Brogna PGS.

6. Production of goat milk and lamb meat enriched in conjugated linoleic acid

The production of goat milk and lamb meat enriched in conjugated linoleic acid (CLA) by feeding focuses on the development of new products with augmented health properties oriented to those consumers who are seeking healthy diets; CLA is a fatty acid that occurs naturally in many foods and it has proven to have positive effects on human health (Chinnadurai and Tyagi, 2011). Results of the iSAGE case studies in Turkey showed that both lamb meat and goat milk CLA content can be enriched with simple feeding regimes (e.g. soybean oil supplemented diets) by keeping additional costs acceptable. Manipulation of the animal's diet resulted in 8 to 10-fold increase in the concentration of CLA in milk. Since consumption of CLA enriched milk could provide considerable benefits for human health, strategies to produce milk with higher CLA content provide new marketing opportunities.

7. Marketing innovations for transhumance dairy products

A label for 'transhumance-origin' dairy products could be a marketing opportunity for dairies. Considering that these products are of higher quality and have been found to have high CLA concentrations (Ioannidou *et al*., 2019), they are expected to be welcomed by consumers who seek healthy diets and lifestyles. In addition, these products are linked to a farming system which provides significant ecosystem services and affects a large part of society interested in environmental quality, tradition and vivid rural areas. In this context, these products could become a relevant marketing asset for small local dairies focusing on the production of specific, local, high-quality, characteristic products, by providing them a significant identity, but also to larger firms that wish to boost their profiles.

- ***Innovations for participatory farmer-group training programmes***

Innovations for participatory farmer-group training programmes is a strategy with high potential to develop a more knowledgeable and competent farming workforce by fostering communication and knowledge exchange in three directions, technicians-farmers, farmers to technicians and farmers to farmers. Flock Health Clubs and Next Generation Ambassador Programmes are examples of such innovations, which have been successfully implemented in UK within the iSAGE project.

8. Flock Health Clubs

Flock Health Clubs aim to improve communication between farmers and veterinarians by encouraging farmers to regularly access cost-effective veterinary advice and vets to enhance

their knowledge, but also between farmers. Specifically, a relevant case study within iSAGE revealed that such clubs improved the relationship between vets and member clients. Farmers trusted and were more willing to contact a knowledgeable vet who was willing to invest time in their flocks. Moreover, these clubs increase farmers' knowledge and encourage them to be proactive about animal health often resulting in productivity benefits. Finally, participating farmers highlight the opportunity to develop and exchange knowledge with other likeminded farmers. One of the most important attributes of this innovation is that it can be extended to any country or farming system. According to the UK experience, such clubs should consist of no more than 25 congenial forward- thinking people, host a minimum of four meetings a year on a range of topics reflecting the season, the issues farmers are facing or factors of importance to the sustainability of the industry and should be rather informal with plenty of time for discussion. However, the main issue here is that disease surveillance across Europe is extremely poor. This means that initiatives cannot rely on good information on disease risks. The notion is that government policies should increase surveillance support.

9. Next Generation Ambassador Programmes

Next Generation Ambassador Programmes focus on developing competent young farmers who stay in the industry and who then become ambassadors for the sector as well as active members of their regional committee. Specifically, each year, a group of 12 successful applicant young farmers receive free, comprehensive training in all aspects of running a healthy flock in a healthy business as well as creating networks of farmers and other industry partners. The iSAGE case studies showed that Next Generation Ambassador Programmes are highly successful at creating supportive networks since members use each other for support and advice suggesting an increase in social sustainability at a regional farm level.

- ***Other innovations***

Innovations relating to any other aspect or problem faced by the sheep and goat industry as a whole or in individual countries/regions are also expected to help towards a more sustainable future. For example, in the iSAGE project the following innovations were also identified and tested:

- **Controlled weaning in organic goat rearing,** as an alternative to standard artificial weaning and with respect to EU organic regulation. This method was tested in a dairy goat farm in Italy and in a dairy sheep farm in Greece. According to the case study results, the controlled weaning method has the potential to produce well developed lambs with non-significant differences in final carcass weight, compared to lambs that are kept constantly with their mothers.
- **Portable milking machine in different farming systems in Turkey.** The results showed that machine milking increases daily milk production of both goat and sheep and reduces the labour force needed but does not have any effect on other milk composition traits. Despite its good performance, the main constrains to the uptake of this technology by farmers in the area is the deficient electricity supply. This is an extreme example of how the socioeconomic conditions of an area, and not the lack of innovation development, are mayor constrains for innovation in sheep and goat farming systems in less favoured areas of Europe.
- **Managing *Haemonchus* burden in lambs using a copper oxide bolus.** This innovation was tested in the UK, with an on-farm trial. The trial was highly innovative for this farm in UK where the presence of *Haemonchus* spp was first identified the previous year when 30 lambs died within 48 hours. The lambs receiving copper supplementation had higher growth rates and this was significant in the first month compared to untreated lambs.

4.5 Strategies for the efficient implementation of innovations

For the adoption and successful implementation of innovations, specific measures and strategies should be developed. Overall, the main challenge of the sheep and goat sector in Europe regarding the implementation of innovations and adoption of best practices, is not the creation of new knowledge, tools, methods and/or techniques, which generally are well-developed and ready available to be implemented, but the socioeconomic and structural constrains that prevent farmer acceptance and uptake of innovations at farm level. Therefore, any research/extension service programme or action aiming at overcoming these constrains will most likely have greater impact on innovation uptake (and therefore in its capacity to adapt to future challenges) than investing in the development of new practices and innovations. Moreover, according to iSAGE innovation case studies, extensive and semi-extensive farming systems appear to face these constrains more than intensive systems. This imbalance is also present among countries and regions. Therefore, innovation strategies should be adjusted to specific features and priorities in individual countries, regions and farming systems.

Strong and well-organized, long-term, farmer collaboration is required for most innovations to be successfully implemented. This is especially true for genetic and breeding innovations and IT technologies on farms sustainability. If farmer collaboration is lacking or is deficient attempts to implement such innovations will most likely be inefficient. The role of farmers' institutions and collective structures (e.g. farmers levy organizations, breeders' associations, cooperatives, etc.) is decisive in regulating and managing such collaboration. Specifically, the efficient implementation of successful breeding techniques and programmes requires a well-organized participation structure characterized by (i) strong and long-term collaboration, (ii) the existence of accurate livestock performance and pedigree recording schemes, (iii) a team of specialized experts in genetics to generate the appropriate tools for the identification and selection of the best breeding animals, (iv) a well-organized structure to spread use of selected animals (live or by AI) across the farmer community, and (v) a common breeding goal set by the farmers participating in the scheme in collaboration with the expert specialists. Likewise, the existence of efficient farmer organizational structures and data recoding schemes along with the support and advice from experienced independent husbandry consultants are needed for the efficient implementation of IT technologies.

A strong vertical sheep and goat value chain integration in inter-branch organizations or any other organizational structure will facilitate the adoption of innovative practices in product development and marketing. Performing an accurate survey of the niche segments of the market that may be interested and estimating the willingness to pay for such products that encompass ethical, environmental and social values is also needed. Moreover, the implementation of participatory farmer-group training programmes requires a national organisation with regional branches, a strong national network of farms, businesses, organisations and key industry people and, moreover, a reliable funding source. This may not be possible in countries where the industry partners and farmers do not have a high degree of organization or where sheep and goats are only reared in specific regions or where small ruminant sector constitutes a minor economic activity.

Finally, iSAGE case studies showed that innovation led by farmers and farmer organizations mainly focus on improving farm and animal performance. Therefore, for farmers to uptake innovations aiming to reduce the environmental impact of their farms, relevant policy signals and intervention of governmental institutions are required. An effective approach would also be for extension programs to emphasize farm innovation that increase farm efficiency (increasing farm profit) and reduce at the same time the farm environmental impact (e.g. PG tool, iSAGEDSS). Moreover, farmer well-being, place of the farmers in the society, quality of products and knowledge of the specificity of small ruminants should be also considered.

IV - Conclusions

The European sheep and goat sector face many technical/social, market, environmental and policy/financial challenges. Outcomes of the iSAGE project produced strategic information for tackling such challenges towards a more sustainable and competitive small ruminant industry. Key findings and recommendations include:

(i) Novel packaging and labelling, new cuts, national origin and PDO products in order to increase consumption of meat and dairy products.

(ii) Enhancing alternative forages (e.g. by-products from agri-food industry) in order to decrease the risks associated with climate change.

(iii) Environmental policies and strategies should consider separating methane from long-lived GHG emissions and using the most updated methodologies and emission factors; small ruminant systems have not caused additional warming to the atmosphere in the last decades.

(iv) Breeding for enhanced animal resilience and adaptability, and region-specific efforts for maximising the use of local breeds.

(v) Industry inspired innovations at all levels to increase the resilience and sustainability of the sheep and goat sector and decrease dependence on public subsidies.

(vi) Adoption and efficient implementation of innovations lies on overcoming the socioeconomic and structural constrains of the sector. Above all, long-term farmer collaboration is crucial for the successful implementation of innovations.

Acknowledgments

This research was funded by the European Union's Horizon 2020 Research and Innovation Action (RIA) through the project 'Innovation for Sustainable Sheep and Goat Production in Europe (iSAGE)', grant number 679302.

References

Al-Dawood A., 2017. Towards heat stress management in small ruminants – A review. *Annals of Animal Science*, 17(1): 59-88.

ANT International, 2011. Evaluation of CAP measures in the sheep and goat sector – Executive Summary. https://op.europa.eu/en/publication-detail/-/publication/168fc925-d44e-4851-8a53-9c8187a4f565

Bateman J.I., Balmford B., 2018. Public funding for public goods: A post-Brexit perspective on principles for agricultural policy. *Land Use Policy*, 79: 293-300.

Belanche A., Martín-García A.I., Álvarez J.F., Pleguezuelos J., Mantecón Á.R., Yáñez-Ruiz, D.R., 2019. Optimizing management of dairy goat farms through individual animal data interpretation. A case study of smart farming in Spain. *Agricultural Systems*, 173: 27-38.

Bernués A., Ruiz R., Olaizola A., Villalba D., Casasús I., 2011. Sustainability of pasture- based livestock farming systems in the European Mediterranean context: synergies and trade-offs. *Livestock Science,* 139: 44–57.

Biscarini F., Nicolazzi E.L., Stella A., Boettcher P.J., Gandini G., 2015. Challenges and opportunities in genetic improvement of local livestock breeds. *Frontiers in Genetics*, 6: 33.

The Cool Farm Tool, 2015. http://www.coolfarmtool.org/.

Chinnadurai K., Tyagi A., 2011. Conjugated Linoleic Acid: A Milk Fatty Acid with Unique Health Benefit Properties. *Soybean and Health*, 111.

Dellar M., Topp C.F.E., Banos G., Wall E., 2018. A meta-analysis on the effects of climate change on the yield and quality of European pastures. *Agriculture, Ecosystems & Environment* 265: 413–420.

Dubeuf J.P., 2014. Science, technology, innovation and governance for the goat sectors. *Small Ruminant Research*, 121(1): 2-6.

Dubeuf J.P., Sayadi S., 2014. Multi-functionality issues for small ruminants: What changes are needed in territorial public policies and training?: Report of two round tables on territorial issues and training for the development of goat farming. *Small Ruminant Research*, 121(1): 136-145.

Dumont D., Andueza D., Niderkorn V., Lüscher A., Porqueddu C., Picon-Cochard C., 2015. A meta-analysis of climate change effects on forage quality in grasslands: specificities of mountain and Mediterranean areas. *Grass and Forage Science*, 70(2): 239-254 doi: 10.1111/gfs.12169

Dýrmundsson Ó.R., 2006. Sustainability of sheep and goat production in North European countries—From the Arctic to the Alps. *Small Ruminant Research*, 62(3): 151-157.

Eisler M.C., Lee M.R., Tarlton J.F., Martin G.B., Beddington J., Dungait J.A., Greathead H., Liu J., Mathew S., Miller H., 2014. Agriculture: Steps to sustainable livestock. *Nature News*, 507: 32.

European Commission, 2019a. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf.

European Commission, 2019b. The Common Agricultural Policy, separating fact from fiction. https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/cap-separating-facts-from-fiction_en.pdf.

European Parliament, 2008. The future of the sheep and goat sector in Europe. https://www.europarl.europa.eu/RegData/etudes/etudes/join/2008/397253/IPOL-AGRI_ET(2008)397253_EN.pdf.

European Parliament, 2017. The sheep and goat sector in the EU. https://www.europarl.europa.eu/RegData/etudes/BRIE/2017/608663/EPRS_BRI(2017)608663_EN.pdf.

European Parliament, 2018a. The future of the EU's sheep and goat sector. https://www.europarl.europa.eu/RegData/etudes/ATAG/2018/620242/EPRS_ATA(2018)620242_EN.pdf

European Parliament, 2018b. Current situation and future prospects for the sheep and goat sectors. https://www.europarl.europa.eu/doceo/document/A-8-2018-0064_EN.pdf.

Forsell N., Turkovska O., Gusti M., Obersteiner M., Elzen M. den and Havlik P., 2016. Assessing the INDCs' land use, land use change, and forest emission projections. *Carbon Balance and Management*, 11: 26.

Forzieri G., Feyen L., Rojas R., Flörke M., Wimmer F., Bianchi A., 2013. Ensemble projections of future streamflow droughts in Europe. *Hydrology and Earth System Sciences*, 10: 10719–10774.

Gerrard C.L., Smith L.G., Pearce B., Padel S., Hitchings R., Measures, M., 2012. "Public goods and farming". In Lichtfouse E. (eds.). *Sustainable Agriculture Reviews: Farming for food and water security*, 10, Springer, pp. 1-22.

Girard N., Bellon S., Hubert B., Lardon S., Moulin C.H., Osty P.L., 2001. Categorizing combinations of farmers' land use practices: an approach based on examples of sheep farms in the south of France. *Agronomie*, 21(5): 435-459.

Guth M., Smędzik-Ambroży K., Czyżewski B., Stępień S., 2020. The Economic Sustainability of Farms under Common Agricultural Policy in the European Union Countries. *Agriculture*, 10(2): 34.

Häni F., Braga F., Stämpfli A., Keller T., Fischer M., Porsche, H., 2003. RISE, a tool for holistic sustainability assessment at the farm level. *International Food and Agribusiness Management Review*, 6(4): 78-90.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

Ioannidou M., Karatassiou M., Ragkos A., Parissi Z.M., Mitsopoulos I., Sklavou P., Lagka V., Samouris, G., 2019. Effects on fatty acids profile of milk from transhumant small ruminants related to the floristic composition of mountainous rangelands. In: Ruiz R., López-Francos A., López Marco L., (eds). *Innovation for Sustainability in Sheep and Goats*, Zaragoza: CIHEAM, 2019. pp. 183-186. (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 123).

Jacob D., Petersen J., Eggert B., Alias A., Christensen O.B., Bouwer L.M., Braun A., Colette A., Déqué, M., Georgievski G., Georgopoulou E., Gobiet A., Menut L., Nikulin G., Haensler A., Hempelmann N., Jones C., Keuler K., Kovats S., Kröner N., Kotlarski S., Kriegsmann A., Martin E., van Meijgaard E., Moseley C., Pfeifer S., Preuschmann S., Radermacher C., Radtke K., Rechid D., Rounsevell M., Samuelsson P., Somot S., Soussana J.-F., Teichmann C., Valentini R., Vautard R., Weber B., Yiou P., 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. *Regional Environmental Change*, 14: 563–578.

Kovats R.S., Valentini R., Bouwer L.M., Georgopoulou E., Jacob D., Martin E., Rounsevell M., Soussana J.F., 2014. Europe. In: Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., White L.L. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1267-1326.

Lu C.D., 1989. Effects of heat stress on goat production. *Small Ruminant Research*, 2(2): 151- 162.

Madsen H., Lawrence D., Lang M., Martinkova M., Kjeldsen T.R., 2014. Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *Journal of Hydrology*, 519: 3634–3650.

Mandolesi S., Naspetti S., Arsenos G., Caramelle-Holtz E., Latvala T., Martin-Collado D., Orsini S., Ozturk E., Zanoli R., 2020. Motivations and barriers for sheep and goat meat consumption in Europe: A means–end chain study. *Animals*, 10(6) : 1105.

Marai I.F.M., El-Darawany A.A., Fadiel A., Abdel-Hafez M.A.M., 2007. Physiological traits as affected by heat stress in sheep—a review. *Small Ruminant Research*, 71(1): 1-12.

Martin-Collado D., Rose G., Diaz C., Zaralis K., Yañez-Ruiz D., 2018. Priority Innovations for European Sheep and Goat Industry Members. In: *Proceedings of the 8th Conference on international and Communication Technologies in Agriculture, Food and Environment (HAICTA 2017)*, Chania, Greece, 21–24 September 2017, pp. 652–657.

Meul M., van Passel S., Nevens F., Dessein J., Rogge E., Mulier A., van Hauwermeiren A., 2008. MOTIFS: a monitoring tool for integrated farm sustainability. *Agronomy for Sustainable Development*, 28: 321-332.

Milán M.J., Arnalte E., Caja G., 2003. Economic profitability and typology of Ripollesa breed sheep farms in Spain. *Small Ruminant Research*, 49(1): 97–105.

Paraskevopoulou C., Theodoridis A., Johnson M., Ragkos A., Arguile L., Smith L.G., Vlachos D., Arsenos G., 2020. Sustainability assessment of goat and sheep farms: a comparison between european countries. *Sustainability*, *12*(8): 3099.

Pulina G., Milán M.J., Lavin M.P., Theodoridis A., Morin E., Capote J., Thomas D.L., Francesconi A.H.D., Caja G., 2018. Invited review: Current production trends, farm structures, and economics of the dairy sheep and goat sectors. *Journal of Dairy Science*, 101 (8): 6715 – 6729.

Rodríguez-Ortega T., Oteros-Rozas E., Ripoll-Bosch R., Tichit M., Martín-López B., Bernuès A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. *Animal*, 8: 1361-1372.

Sawyer G.J., 1979. The influence of radiant heat load on reproduction in the Merino ewe. II. The relative effects of heating before and after insemination. *Crop and Pasture Science*, 30: 1143–1149.

Soussana J.F., Hartwig U.A., 1995. The effects of elevated CO2 on symbiotic N2 fixation: a link between the carbon and nitrogen cycles in grassland ecosystems. *Plant and Soil*, 187(2): 321- 332.

Theodoridis A., Ragkos A., Zaralis K., Smith L., Arsenos G., 2019. Towards a pan-European typology of sheep and goat farms: A meta analysis. In: Ruiz R., López-Francos A., López Marco L., (eds). *Innovation for Sustainability in Sheep and Goats*, Zaragoza: CIHEAM, 2019. pp. 65-69. (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 123).

Villalba D., Díez-Unquera B., Carrascal A., Bernués A., Ruiz R., 2019. Multi-objective simulation and optimisation of dairy sheep farms: Exploring trade-offs between economic and environmental outcomes. *Agricultural Systems*, 173: 107-118.

Vouraki S., Skourtis I., Psichos K., Jones W., Davis C., Johnson M., Riaguas Rupérez L., Theodoridis A., Arsenos G., 2020. A decision support system for economically sustainable sheep and goat farming. *Animals*, 10(12): 2421.

Volaire F., Norton M.R., Lelievre F., 2009. Summer Drought Survival Strategies and Sustainability of Perennial Temperate Forage Grasses in Mediterranean Areas. *Crop Science*, 49: 2386-2392.