Sheep and goat pox: vaccines and vaccination scenarios to control the epidemics in Greece and Bulgaria in 2025

European Food Safety Authority (EFSA), Tsviatko Alexandrov, Ieva Baltusyte, Alessandro Broglia, Paolo Calistri, Simon Gubbins, Nick De Regge

Abstract

Sheep pox and goat pox (SGP), caused by *Capripoxviruses*, have reemerged in Europe with unprecedented intensity during 2024–2025, particularly affecting Greece and Bulgaria and posing an increasing risk to neighbouring countries. Despite established EU control measures, the scale and persistence of outbreaks may suggest certain delays in detection or reporting and a potential role of animal movements, both authorised and uncontrolled, in sustaining transmission. This assessment reviews the effectiveness and safety of commercially available SGP vaccines and evaluates the potential impact of vaccination strategies on epidemic control and eradication. A literature review and experimental data from the EURL for *Capripoxviruses* confirm that live attenuated SGP vaccines based on sheep pox virus strains, including RM65, Romania, and Bakirköy sheep pox strains, provide strong protection (typically 80–100%) and substantially reduce viral replication and shedding in sheep. Safety profiles are generally favourable, though mild post-vaccination reactions may occur, and adherence to recommended dosing is essential. The risk of vaccine virus transmission is minimal when standard precautions are followed. Using demographic and outbreak data from Bulgaria, a stochastic spatial kernel model was applied to simulate SGP spread and assess vaccination scenarios. Results indicate that rapid detection and culling alone can control epidemics within 1–2 years, but vaccination markedly reduces outbreak size and geographic spread. Regional vaccination carries a risk of viral escape unless strict movement controls are enforced, whereas nationwide vaccination provides more robust containment. A two-year vaccination campaign combined with standard control measures is predicted to achieve eradication one year earlier than non-vaccination strategies. In Greece, the complexity of transmission dynamics and multiple epidemic clusters suggest that targeted or nationwide vaccination would be necessary. Overall, vaccination—particularly when integrated with early detection, rapid culling, and movement restrictions—offers a critical tool for controlling and potentially eliminating SGP in affected regions.

Keywords: sheep and goat pox, *Capripoxviruses*, vaccination, kernel modelling, epidemic spread, spatio-temporal analysis

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1 Introduction

1.1 Background and Terms of Reference as provided by the requestor

Sheep pox and goat pox (SGP) are viral diseases affecting sheep and goats, caused by strains of the *Capripoxvirus*. All strains of this virus can infect both species, although most tend to cause more severe clinical symptoms in either sheep or goats. The disease is typically characterized by fever, widespread papules or nodules, and occasionally vesicles, internal lesions, or even death. In indigenous animals, the occurrence of generalized disease and mortality is often lower, even in areas where the disease has been absent for extended periods.

SGP is endemic in regions such as northern Africa, the Middle East, Türkiye, and parts of Asia. Although considered exotic to the European Union, several outbreaks have occurred in recent years. Since 2013, cases have been reported in Greece and Bulgaria, with further outbreaks emerging in Spain, Romania, Greece, and Bulgaria since 2022. The current epidemics in Greece and Bulgaria have now reached a worrying scale.

Given the epidemiological situation, and despite the implementation of effective control measures under the EU legal framework for animal health, veterinary authorities in the affected countries have requested scientific guidance on the possible use of vaccination as an additional control tool. EFSA already assessed SGP vaccines in a 2014 scientific opinion, concluding that homologous live attenuated vaccines available provide good protection and safety and are effective in controlling outbreaks when a minimum coverage of 75% is achieved and maintained.

However, the competent authorities in Bulgaria and Greece have now raised new questions related to the selection of suitable vaccine strains, the design and duration of vaccination campaigns, and the expected impact of different vaccination scenarios on disease spread and eradication.

1.1.1 Terms of Reference

In accordance with Article 31 of Regulation (EC) No 178/2002, the European Commission requests EFSA to:

1. **Review the commercially available vaccines for sheep and goat pox**, in particular, to:
    - Assess their effectiveness (in terms of reduced susceptibility to infection/disease and reduced infectiousness).
    - Evaluate their safety (side effects on vaccinated animals and potential shedding of the vaccine strain);
    - Compare, where possible, the performance of the *Jovivac* (RM-65) vaccine with the Turkish self-produced vaccine.
    - Involve, where relevant, the EURL on *Capripoxviruses* and, the European Medicines Agency (EMA).
2. **Assess the impact of vaccination on the spread and eradication of SGP**, considering:
    - Available data on animal population distribution, outbreak data, and animal movements (noting limitations related to unrecorded movements). Bulgaria and Greece should provide EFSA with data and information on the target animal populations, outbreaks, since the beginning of the current epidemics, including the results of epidemiological investigations.
    - Different epidemiological and vaccination scenarios, including regional and country level vaccination strategies (e.g. limited to affected areas in Bulgaria).

- Possible incursions of infected animals in a population of sheep and goats during the vaccination period.
- The duration of vaccination campaigns needed to achieve eradication.

1.2 Interpretation of the Terms of Reference

The effectiveness and safety of SGP vaccines[1] is addressed in section 3.2 of the present report. Both evidence from the literature and experimental trials performed by the EURL on *Capripoxviruses* are considered. In the discussion, conclusions and recommendations, only the strains from commercial vaccines are considered (basically all live attenuated vaccines, including RM-65 and the Turkish self-produced strain), and heterologous, recombinant vaccines are excluded. The European Medicine Agency (EMA) was consulted. However, there are currently no vaccines against SGP authorised in the EU; therefore, direct data on specific products is not available on their use in the EU. Nevertheless, commercial vaccines are available elsewhere.

Regarding term of reference 2, available data on animal population distribution and outbreak data were provided by the national authorities of Bulgaria and Greece. Firstly, an analysis of the epidemiological situation in both countries is provided, including discussion of risk factors for transmission, areas most at risk, the structure of the small ruminant population and epidemic clusters.

Based on the available outbreak data and previous information on SGP epidemics in the region considered a kernel[2] was fitted to the available outbreak data to simulate the spread and possible vaccination strategies. Those scenarios include regional and country vaccination strategies as well as possible incursions of infected animals in at-risk areas. The latter aspect simulates the impact of uncontrolled animal movements, since data on unrecorded animal movements are not available, while authorised movement of animals within restriction zones is prohibited and should not occur. Based on the same model, the duration of vaccination campaigns needed to achieve eradication is computed.

1.3 Additional information

Additional information about the epidemiological development and prevention of SGP epidemics and control measures applied in Bulgaria and Greece was provided by the national authorities from Greece and Bulgaria.

[1] *For their use according to Article 110 (2) of Regulation (EU) 2019/6*. The EFSA experts do not perform an assessment of vaccines that could lead to a recommendation for a Veterinary Medicinal Product.

[2] A kernel spread model is a type of spatial or spatio-temporal model that uses a mathematical function (the "kernel") to describe the probability or intensity of disease transmission between locations based on the distance between them.

2 Data and Methodologies

2.1 Data and methodology

2.1.1 Vaccines

The effectiveness and safety of the vaccines against sheep and goat pox was assessed based on data from the literature and from experimental data from the EURL for *Capripoxviruses*.

A literature review was performed on both aspects, on vaccine effectiveness (Annex 1 at www.zenodo.org/uploads/18439931) and on vaccine safety (Annex 2 at www.zenodo.org/uploads/18374862) using the Elicit search engine[3]. The review questions were defined by EFSA and reviewed by WG experts. The papers were retrieved by using the Elicit search engine and screened by EFSA, based on the title and abstract. The list of selected papers was submitted to WG experts for check and possible inclusion of additional papers. The variables for the data extraction were defined by Elicit and reviewed by EFSA WG of experts. Data extraction was based on 112 full text papers and on 27 title and abstracts out of 139 papers for vaccine effectiveness, and on 54 full text papers and on out of the 113 on vaccine safety. Additionally, EFSA checked the full text of the most relevant 73 papers and amended or specified the outcomes if needed. The results and conclusions were drafted by the EFSA WG of experts, based on the data extraction table obtained from Elicit and reviewed by EFSA WG.

EURL experiments were conducted on sheep with sheep pox vaccines.

2.1.2 Epidemiology of SGP and vaccination scenarios

Demographic data for Bulgaria and Greece were obtained from the national veterinary services. These provided the number of sheep and goats in each herd and the location of the herd (latitude and longitude). National authorities also provided information about risk factors for SGP introduction and spread, areas at risk in each country, and possible vaccination plans. Outbreak data were obtained from the Animal Disease Information System (ADIS)[4]. The national veterinary services also provided an estimate of the annual replacement rate, which was 20%.

Descriptive epidemiology and cluster analysis was used to describe the epidemics of SGP in 2024-2025 in Greece and Bulgaria.

A simple stochastic spatial model was used to describe the transmission of SGPV between farms. All farms with small ruminants (i.e. sheep and goats) were included in the model. For simplicity, seasonal fluctuations in the sheep and goat populations (due to lambing and kidding, respectively) were ignored in the model. Spread between farms was described using a kernel-based approach (EFSA, 2018; EFSA AHAW Panel, 2014). In this case, the force of infection (i.e. the rate at which susceptible farms become infected) for farm *j* at time *t* is given by:

$$\lambda_j(t) = hS_j \sum_{k \neq j} I_k(t) K(x_{jk})$$

where *h* is the baseline risk, $S_j(t)$ is the number of susceptible animals in farm *j*, $I_k(t)$ is the number of infected animals on farm *k* and *K* is the distance kernel and x_{jk} is the great circle distance between farms *j* and *k*. The following functional form for the kernel was used:

[3] www.elicit.com

[4] https://food.ec.europa.eu/animals/animal-diseases/animal-disease-information-system-adis_en

$$K(x) = \left(1 + \frac{x}{d_0}\right)^{-\alpha}$$

where d_0 is the distance scaling and α is the kernel power.

For Bulgaria parameters were estimated using maximum likelihood methods (EFSA AHAW Panel et al., 2021) applied to data on outbreaks in Bulgaria reported after 29 June 2025 and within 50 km of the initial incursion location. The latter restriction was to avoid biasing estimation of the kernel because of long distance jumps of the virus. The estimated parameter values used in the simulations were h=4.73×10^{-6}, d_0=1.25 and α=2.79.

For Greece, preliminary analysis of outbreak data using the same methods failed to produce reliable estimates for the kernel parameters to be used when simulating the spread of SGP. This remained the case even when restricting the analysis to spatially and temporally restricted data sets reflecting different outbreak clusters. Furthermore, initial simulations of spread in the whole of Greece indicated that a simple distance-based kernel model cannot easily take into account natural barriers to disease spread presented by the mountainous regions and numerous islands. Accordingly, with the data currently available and, above all, within the timeframe for performing this assessment, the kernel-based model was not used to further to investigate the spread of SGP or the impact of vaccination in Greece. To model the Greek situation would require detailed animal movement data and the construction of a more complex model, which takes into both within-farm dynamics and allows for spread between farms via livestock movements as well as via local spread.

Consequently, given the urgency of the request and the time available, the assessment of the vaccination scenarios for Greece was based on descriptive spatio-temporal analysis of the epidemiological data.

Within each farm, small ruminants were divided into four classes, susceptible (i.e. uninfected) (S), infected (I), recovered (R) and vaccinated (i.e. uninfected and temporarily protected) (V) animals, with the number in each class recorded. If the farm became infected, the within-farm dynamics of SGPV were not explicitly simulated, rather the number of infected animals (I) was drawn from a binomial distribution with population S (i.e. the number of susceptible animals) and probability f, the final size of the outbreak. For an SIR model this is given by the non-zero root of the equation

$$1 - f - exp(-fR_0) = 0$$

where R_0 is the within-herd basic reproduction number (Keeling & Rohani, 2008). A herd was assumed to be infectious for the duration of its outbreak. Three scenarios were considered for this: (i) 15 days: rapid detection and culling of infected farms, so duration is one incubation period (10 days) (EFSA AHAW Panel, 2014) and the time between reporting and culling estimated by the Bulgarian veterinary services (5 days); (ii) 30 days: normal detection and culling, so duration is 2-3 incubation periods (25 days) and the time from reporting to culling (5 days); or (iii) 60 days: no control, so duration is based on the mean duration of simulated within-herd outbreaks (EFSA AHAW Panel et al., 2021).

When vaccination was modelled, all farms and all animals on a farm were assumed to be vaccinated (i.e. vaccination was compulsory). Susceptible (i.e. uninfected) animals were assumed to be protected, with the probability given by the vaccination effectiveness (i.e. the proportion of vaccinated animals that were protected from infection under field conditions), while infected and recovered animals were unaffected by vaccination (reflecting lifelong immunity assumed to occur following natural infection). If animals were revaccinated in subsequent years, they were assumed to remain protected, while if the vaccination campaign stopped, all vaccinated animals were assumed to become susceptible again (i.e. the duration of immunity was assumed to be 1 year). Vaccine effectiveness was assumed to be 95% (EFSA, 2018).

Vaccination was assumed to be used in either four regions (specifically Plovdiv, Haskovo, Stara Zagora and Pazardzhik) or the whole country. In both cases, vaccination was assumed to start 90 days after the introduction of SGPV. Based on estimates from Bulgarian veterinary services, farms were assumed to be vaccinated at a constant rate such that all farms had been vaccinated after 60 days.

3 Assessment

3.1 Vaccines against SGP

Worldwide, a variety of live attenuated and inactivated vaccines has been extensively used for long time to provide protection against sheep pox and goat pox in endemic countries and in regions where SGP has a spread at large scale spread and high impact on livestock, e.g. many countries in Africa, Asia, Middle East (Bamouh et al., 2023; Bianchini et al., 2025; EFSA AHAW Panel, 2014; Tuppurainen et al., 2017). Vaccines are based on several strains for example the Romanian, RM-65 or Bakirkoy SPP strains or Mysore and Gorgan GTP strains. A single strain of capripoxvirus is consider conferring cross protection to protect both sheep and goats against all field strains of virus, but field evidence suggests some strains are quite host-specific and could give better results if used only in sheep against SPPV and only in goat against GTPV (WOAH, 2024).

Live vaccines are primarily used due to the longer immunity they confer and due to the limited commercial availability of killed alternatives, which provide only temporary immunity. There are no commercially available vaccines against SGP with a Differentiation of Infected from Vaccinated Animals (DIVA) component.

3.1.1 Literature review about vaccine effectiveness

A literature review was run on Elicit 9th November 2025 using the query "How do different vaccine types reduce morbidity and mortality rates in sheep and goat populations exposed to sheep pox virus?" across papers from Semantic Scholar and OpenAlex. 497 papers were retrieved and 139 papers were selected by the EFSA WG of experts, based on the title and abstract. Further details about the literature review including the data extraction table are available as Annex 1 at this link www.zenodo.org/uploads/18439931.

The information extracted from the selected papers included:

- study design: experimental challenge, field trial, review;
- vaccine type: live attenuated vaccines, inactivated vaccines, combination vaccines, recombinant vaccines, heterologous vaccine);
- target species: sheep, goats, cattle, mice, small ruminants (not further specified);
- primary outcomes measured: protection or clinical/field protection, antibody response, morbidity and/or mortality, efficacy, duration of immunity or protection, field effectiveness, economic impact.
- other outcomes: e.g., immune response, breed susceptibility, PCR, genetic analysis, etc.

Out of the papers selected, 73 target sheep and goats as study species and report vaccination against SGP as protective intervention, and 64 out of 73 included the study design as above, either on controlled trials or field trial (52) or review (12). 55 papers out of the 64 reported protection of vaccination against SGP. The remaining 7 papers only report immunological outcomes (seroconversion, antibody titers) rather than clinical effectiveness (Amanova et al., 2021; Darwish et al., 2024; Hurisa et al., 2024; Sareyyüpoğlu et al., 2022; Shafik et al., 2017).

3.1.1.1 Outcome on morbidity and mortality reduction

- Live attenuated vaccines: Most included studies reported that these vaccines consistently reduce morbidity and mortality to near zero in vaccinated indigenous breeds.
- Inactivated vaccines: These vaccines were reported to provide similar reductions in morbidity and mortality, with improved safety profiles in the studies that evaluated them.
- Combination vaccines (including bivalent vaccines targeting two pathogens): These were reported as effective in reducing both morbidity and mortality.
- Unvaccinated controls: In challenge studies, unvaccinated controls consistently showed high morbidity (up to 100%) and mortality (up to 72%) as reported in the included studies.

3.1.1.2 Outcome on duration of protective immunity

- Live attenuated vaccines: Protection was reported to last up to 52 months in goats (Bhanuprakash et al., 2021; 2022), and at least 12 months in sheep (Amanova et al., 2021).
- Inactivated vaccines: Antibody responses and protection were reported to last up to 9 months (Boumart et al., 2016).
- Maternal immunity: One study reported that maternal immunity lasts approximately 60 days in lambs (Ebrahimi-Jam et al., 2022).
- Annual boosters: Some studies recommended annual boosters, especially in young or high-risk populations.

3.1.1.3 Conclusions

- Effectiveness:
    - Live attenuated vaccines: Efficacy ranged from 80–100% in most studies.
    - Inactivated vaccines: Efficacy was reported as 100% in some studies using high doses.
    - Combination/bivalent vaccines: Efficacy was 100% in most studies.
    - Recombinant/DNA vaccines: Efficacy ranged from partial to full, but only limited data were available.
- Economic impact: several studies noted that vaccines eliciting long-lasting protection (e.g. live vaccines) and bivalent formulations (vaccines targeting two pathogens) are more cost-effective, reducing the need for frequent boosters and minimizing production losses. However, direct cost data were limited.
- Performance modifiers: breed, age, physiological status (such as pregnancy), timing of vaccination, and coverage rates were identified as critical determinants of vaccine effectiveness.
- Limitations of the evidence base: many studies were small, lacked detailed reporting on quantitative effect of vaccines, or were only available as abstracts, limiting assessment of risk of bias and generalizability. There is a need for more large-scale, randomized field trials and economic evaluations to strengthen the evidence base. The experiments conducted by EURL in controlled environment on sheep vaccinated by sheep pox vaccines can fill this gap with more experimental evidence.

- Nevertheless, besides the trials reported in the literature, in term of amount of field evidence of SGP vaccine effectiveness, in endemic countries such as in Africa, the Middle East and Asia where SGP impacts severely on small ruminant population, vaccination with live attenuated strains has been widely used as effective strategy to control SGP outbreaks where sufficient vaccination coverage is achieved (Bianchini et al., 2025).

3.1.2 Literature review about vaccine safety

Concerns about the safety of live-attenuated vaccines often center on three key aspects:

- Severity of adverse reactions,
- Risk of vaccine virus shedding, and
- Safety in pregnant animals.

A literature review was run on 26th November 2025 on Elicit using the query "Are commercially available vaccines against sheep and goat pox safe in terms of severity of adverse reactions, risk of virus shedding and compatibility with pregnancy of animals?". 174 papers were retrieved and screened and 113 papers most relevant to the question were selected, based on the title and abstract. The information extracted from the selected papers included vaccine details, study design, animal population, adverse reactions, virus shedding, pregnancy safety. Details about the literature review are available as Annex 2 (literature review report and data extraction at this link www.zenodo.org/uploads/18374862).

Also, recent research (2024–2025) provides updated evidence on these safety aspects, particularly from controlled trials in non-endemic and endemic regions (Bianchini et al., 2025; Esmaeili et al., 2024; Nizeyimana et al., 2025).

3.1.2.1 Adverse reactions

In the screened literature, 17 papers clearly reported no adverse or very mild (e.g. transient swelling at inoculation site) effect in animals vaccinated with live SGP vaccines (8 papers considering SPP vaccine in sheep, and 3 in sheep and goats; 5 papers considering GTP vaccine in goats or sheep and goats). On the contrary only three papers reported some degree of adverse effects (e.g. depression, loss of appetite, laboured breathing) in sheep and goats vaccinated with live vaccines (2 papers with GTP vaccine in goats, one paper with SPP vaccine in sheep) (Achour et al., 2000; Esmaeili et al., 2024; Esmaeili et al., 2025). These adverse reactions varied widely depending on the vaccine type and strain, the animal species and breed, and dose administered.

Also, in the previous EFSA opinion on sheep and goat pox and other review on capripoxvirus and in particular SGP vaccines, no safety issues were identified in the vaccines based on three most used live attenuated SPP strains (RM-65, Romanian and KSGP 0240) (Bamouh et al., 2023; EFSA AHAW Panel, 2014; Hamdi et al., 2021; Tuppurainen et al., 2017).

Co-administration of PPR, CCPP, SGPX, and Pasteurellosis vaccines in goats produced no observable adverse effects (Hurisa et al., 2024).

Comparative studies in sheep demonstrated that inactivated sheep pox vaccines caused only transient, mild injection site inflammation, whereas live attenuated vaccines produced more prolonged local swelling (up to 20 days) and mild systemic fever occurring 6–8 days after vaccination (Boumart et al., 2016). For comparison, dose escalation work in cattle using the G20LKV goat pox vaccine showed that high doses (60,000–80,000 TCID50) produced noticeable injection site swelling, while lower doses caused no adverse reactions, indicating a clear dose–response relationship (Abitaev et al., 2022).

Amanova et al (2022) reported some results with sheep pox vaccine (NISHI strain) on sheep of the Kazakh fine-wool breed (6 to 12 months age). On days 7, 14, and 21 after administration neutralizing antibodies in the vaccinated animals ranged from 1.8 to 4.33 $\log_2$, while no antibodies in the control sheep. The vaccinated animals remained healthy, except for swelling at the injection site of the virulent virus in 3 sheep (1.0 × 1.2 cm), which resolved 3–4 days after infection. The body temperature of the sheep remained within the physiological norm (Amanova et al., 2022). Similar findings were in another study of the same authors with combined live attenuated PPR (Nigeria strain 75/1) and sheep pox vaccine (Niskhi strain), where only 3 out of 6 vaccinated sheep showed transient small swelling (0.5 cm) at injection site (Amanova et al., 2021).

Some adverse effects were detected in two studies by Esmaeili et al (2024, 2025) conducted with GTP strain in pure-breed goats. A 2024 controlled study in pregnant Murcia-Granada goats showed that standard-dose of live-attenuated GTPV (Gorgan goat pox strain) vaccine prepared at Razi Vaccine and Serum Research Institute (RVSRI) in Iran (not commercially available vaccine) caused no clinical reactions or abortions, while a double-dose triggered abortions in 37% of animals and detectable vaccine strain viremia (Esmaeili et al., 2024). This confirms the vaccine's safety at standard dose but highlights dose-dependent risk. The same author showed that in Saanen goats, inactivated goat pox vaccines produced only mild local lesions in a small proportion of animals (2–18.66%), whereas live attenuated GTP vaccines (same as above) caused severe pox lesions in most vaccinated goats (82%), along with systemic signs such as depression, reduced appetite, and laboured breathing. These reactions appeared 18–25 days post-vaccination and persisted for up to two weeks, highlighting a substantial difference in reactogenicity between vaccine types, and that safer vaccines or inactivated GTP vaccines should be rather used in certain pure goat breeds (Esmaeili et al., 2025).

Some comparative efficacy studies also noted safety differences among live strains. For example, the SPPV-R strain was reported to be insufficiently attenuated and associated with excessive adverse reactions, whereas SPPV-Srin and SPPV-RF strains were considered safe, though detailed reaction profiles were not provided (Yogisharadhya et al., 2011).

3.1.2.2 Virus shedding

Virus shedding of SGP vaccine virus is rarely documented. In the literature review, nine papers clearly reported outcome on presence/absence of shedding of vaccine virus. Six of those reported absence of virus shedding in vaccinated animals (Amanova et al., 2021; Balinsky et al., 2007; Chaudhary et al., 2009; Haegeman et al., 2016; Ramyar & Hessami, 1967; Yogisharadhya et al., 2011), two papers reported presence of virus shedding indicated by positive isolation and detection of SGP, (Esmaeili et al., 2024; Ghander et al., 2020). PCR monitoring in Esmaeili et al. (2024) confirmed that shedding of the vaccine virus was detectable only in over-dosed animals; standard-dose groups showed no evidence of viral shedding. This suggests minimal transmission risk under recommended use. An old paper by Davies (Davies, 1976) reported shedding of experimental vaccine virus from vaccinated to unvaccinated animals.

Inactivated vaccines pose no risk of shedding, making them preferable for disease-free zones and sensitive populations.

3.1.2.3 Compatibility with pregnancy

Out of the screened literature, seven papers clearly reported on presence/absence of any effect on pregnancy of sheep or goats or on lactating lambs or kids. 4 studies (2 in sheep and 2 in sheep and goats) showed normal lambing without virus shedding in vaccinated animals(Abd-Elfatah et al., 2019; Bamouh et al., 2023; Fanar A. Isihak & Y.Al-Attar, 2016; Précausta et al., 1979), while only one paper reported abortions goats vaccinated with double dose of experimental GTP vaccine (Esmaeili et al., 2024, see at section 3.1.2.1 above). The study reported that pregnant goats receiving a standard dose of vaccine completed gestation without abortion or neonatal abnormalities, indicating good compatibility with pregnancy. However, overdosage or stress conditions can compromise placental integrity and induce abortion. Two papers reported on maternal antibody transfer to offspring from vaccinated ewes or does (Abdollahi et al., 2024; Ebrahimi-Jam et al., 2022).

Live sheep pox vaccines (e.g., RM-65 strain) are generally safe in pregnant ewes, resulting in normal lambing and no virus shedding. Goat pox vaccines are to be avoided in pregnant animals unless safety is confirmed, since high-dose exposure linked to abortions.

A global review of sheep and goat pox epidemiology (2005–2022) highlighted that live-attenuated vaccines are effective and safe when administered correctly, though breed-specific sensitivity and environmental stressors remain important modifiers (Bianchini et al., 2025).

3.1.2.4 Conclusion

Overall, the evidence from the literature screened indicates that commercially live-attenuated sheep and goat pox vaccines are generally well-tolerated when used at standard dosages, showing negligible vaccine virus shedding, and compatibility with pregnancy. However, certain strains, overdosing, stress, breed susceptibility or improper administration can cause some adverse effects. Routine safety monitoring and adherence to manufacturer recommendations are essential to prevent complications in pregnant animals. In general, all live attenuated vaccines may induce certain degree of adverse effects, these should be evaluated by running preliminary vaccination trials.

Inactivated and recombinant vaccines were reported to have improved safety profiles, although none of these is currently commercially available in the EU, moreover inactivated vaccines induce short-term immunity and would require periodic booster doses.

3.1.3 EURL experimental trials

The EURL for Capripox viruses performed a series of experimental trials to assess safety and efficacy aspects of three sheep pox vaccine strains, i.e. RM-65, Romanian and Bakirköy strains. Here below the main results of these experiments are summarised, for details it should be referred to a dedicated publication that will be soon available[5].

The experiments were conducted on sheep with 2 different commercial vaccines for each strain. The vaccines were checked to be free of contaminating viruses and bacteria, and all contained a vaccine virus dose higher than $10^{2.5}$ $TCID_{50}$/dose, being the minimum dose recommended by WOAH. The number of trials per strain, the number of sheep used, the type of signs recorded for the safety trials (i.e. fever higher than 41°C, severe local lesions, nasal vaccine shedding, viremia), the outcomes for the efficacy trials (i.e. mortality, morbidity, nasal shedding, viremia) are reported in Table 1 and Table 2.

[5] https://www.eurl-capripox.be/

Table 1. Safety outcomes of vaccination trials at EURL for Capripoxvirus

	#vaccines	#trials	# animals (sheep)	fever >41°C		severe local lesions		nasal vaccine shedding				viremia			
				#	%	#	%	#	%	duration (mean days/animal)	Intensity [a]	#	%	duration (mean days/animal)	Intensity [a]
RM-65	2	4	36	26	72	18	50	7	19	1	39.51	8	22	1.5	39.56
Romania	2	3	28	23	82	17	61	4	14	1.5	36.75	10	36	1.8	39.03
Bakirköy	2	2	28	1	4	0	0	17	61	1.1	39.69	11	39	1.6	38.02

Table 2. Efficacy outcomes of vaccination trials at EURL for Capripoxvirus

	#vaccines	trials	# animals (sheep)	mortality		Morbidity [b]		nasal shedding				viremia			
				#	%	#	%	#	%	duration (mean days/animal)	Intensity [a]	#	%	duration (mean days/animal)	Intensity [a]
unvaccinated control animals			20	20	100	20	100	18	90	2,65 [c]	27.2	20	100	6 [c]	31.6
RM-65	2	2	18	0	0	0	0	11	61	2.54	39.16	0	0	0	N/A
Romania	2	2	18	0	0	0	0	6	33	3.16	38.54	1	6	1	39.02
Bakirköy	2	2	28	0	0	6 [d]	21	25	89	3.2	36.57	5	18	4.8	36.85

a) Mean lowest Ct
b) at least one of following clinical signs: severe reaction inoculation site, local or generalized nodules, fever >41°C, severe other clinical disease score (general condition, respiratory problems, etc.)
c) underestimation since viraemia and nasal shedding were ongoing at moment of euthanasia
d) 6 animals showing clinical signs, including 2 animals that developed a short but high fever (>41°C) and 4 animals with a strong local reaction of which 2 developed a limited number of nodules which disappeared within 3 days

3.1.3.1 Safety

RM-65 and Romanian strains induced fever above 41°C for at least one day (>70% of animals) and severe local swelling at the vaccination site (>50% of animals) in a majority of sheep. Similar observations have been made in other studies (EFSA AHAW Panel, 2014). On the other hand, vaccination with Bakirköy strain induced minimal fever and lesions, indicating a better safety profile.

All strains caused short viremia (1–2 days on average) with very low mean viral loads close to the detection limit.

Concerning the nasal shedding, 10–20% of animals vaccinated with RM-65 and Romanian strains shed vaccine virus briefly, while 61 % of those vaccinated with Bakirköy shed virus, but only for 1–2 days on average at low levels. The short and low viremia and nasal shedding of vaccine virus were detectable by qPCR after vaccination, but the obtained Ct values were close to the detection limit, indicating that it concerned very low viral loads, making that onward transmission of these vaccine strains is highly unlikely.

Overall, the risk of transmission was judged negligible if animals remain on farm for three weeks post-vaccination, the time necessary to develop the protective immune response. Bakirköy, Romania and RM-65 strain-based vaccines were considered safe since none of them induced typical 'sheep pox-like' clinical signs.

3.1.3.2 Efficacy

A virulent SPPV Moroccan strain was used as challenge virus (Zro et al., 2014) and administered at a dose between $10^{3.3}$ and $10^{4.95}$ $TCID_{50}$/animal. When intradermally inoculated, all 20 unvaccinated control sheep needed to be euthanised for welfare reasons due to severe disease before the foreseen end of the trial (21 days post challenge). This challenge was considered highly stringent seen the use of a high virulent strain, high inoculation dose, and intradermal administration and it is therefore estimated that the mortality and morbidity observed in vaccinated animals represent a worst-case scenario. It is expected that challenge under field conditions would be less severe and the observed vaccine efficacy under field conditions would (even) be better.

The animals vaccinated with RM-65 and Romanian strains showed 100% protection against mortality and morbidity, without any clinical signs. Those vaccinated with Bakirköy showed 100% protection against mortality, 21% of those showed mild morbidity (short fever, severe local reaction and/or localized lesions). Lesions were minimal, transient, and unlikely to be detected in field conditions.

Concerning nasal shedding of challenge virus, vaccinated animals showed ~1000-fold reduction compared to controls. Overall, there are limited published data on vaccine virus excretion, and the findings from these trials are in line with what previously reported (EFSA AHAW Panel, 2014). RM-65 and Romanian strain vaccines protected almost completely against viremia after challenge. Using the Bakirköy strain, some challenged animals (20%) had a detectable viremia (4-5 days), but viral loads were ~100 fold lower than in controls.

3.1.3.3 Conclusion

- All three vaccines provided full protection against mortality.
- RM-65 and Romania strains also provided complete protection against morbidity but are less safe (fever, reaction at vaccination site). It may be important to warn farmers in advance for these side-effects.
- Bakirköy strain is safer and still offers strong protection. A limited morbidity occurred in a small (20%) subset of sheep after challenge . This morbidity included a high fever for at least one day

in some animals or a severe reaction at the challenge site. Some of these animals developed a few small nodules which quickly disappeared. Since a very stringent challenge was applied in our study, it is questionable whether this would also occur with an SPPV infection under field conditions.

- Transmission risk of vaccine virus is very low and could be further reduced by avoiding contact with unvaccinated animals up to three weeks post-vaccination, until protective immunity is induced.
- Vaccination with all three vaccine strains resulted in a strong reduction of viremia and nasal virus shedding. Detected viral DNA loads in nasal swabs were about 1000-fold lower than in non-vaccinated animals and close to the detection limit.
- Overall, vaccines are effective tools for controlling sheep pox, with the Bakirköy vaccine offering the best safety profile and RM-65 and Romanian vaccines offering the best efficacy profile.

3.2 SGP epidemics in Greece and Bulgaria

An analysis of the epidemiological situation in both countries is provided in this section, including structure of the small ruminant population, description of SGP spread patterns in the region, risk factors for transmission, areas most at risk. Furthermore, an analysis of epidemic clusters is provided in section 3.2.3.

3.2.1 Small ruminant population in Greece and Bulgaria

To understand certain epidemiological pattern of the SGP epidemics, a description of the small ruminant population structure in Greece and Bulgaria is provided in this section.

The small ruminant population in Greece and Bulgaria comprise 83,500 farms (approx. 17 million heads, 13 million sheep and 4 million goats) and 24,300 farms (1.4 million heads, 1.23 million sheep and 200 thousand goats) respectively.

The density of farms and animals is displayed in Figure 1 and Figure 2.

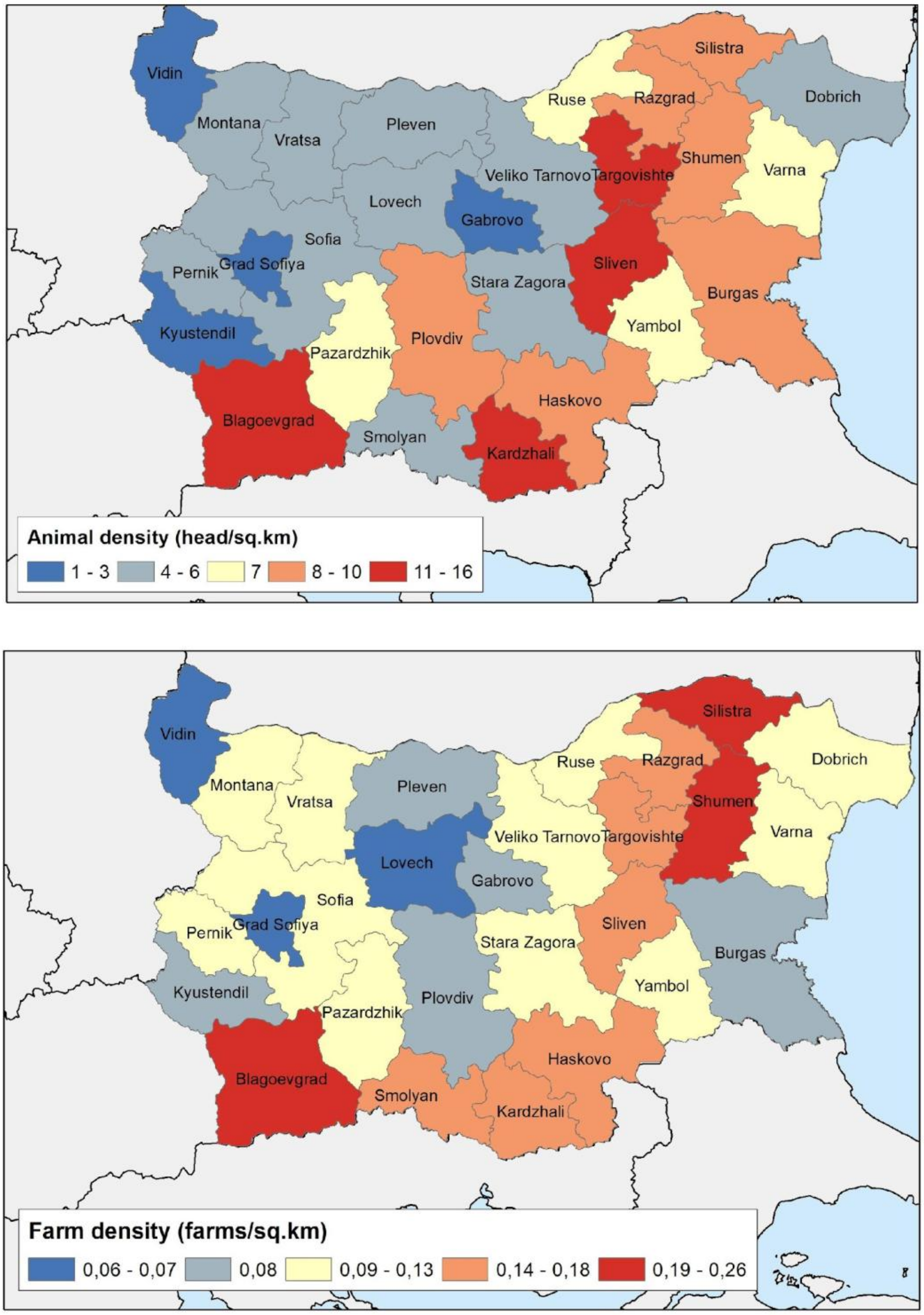

Figure 1. Animal and farm density of small ruminants in Bulgaria

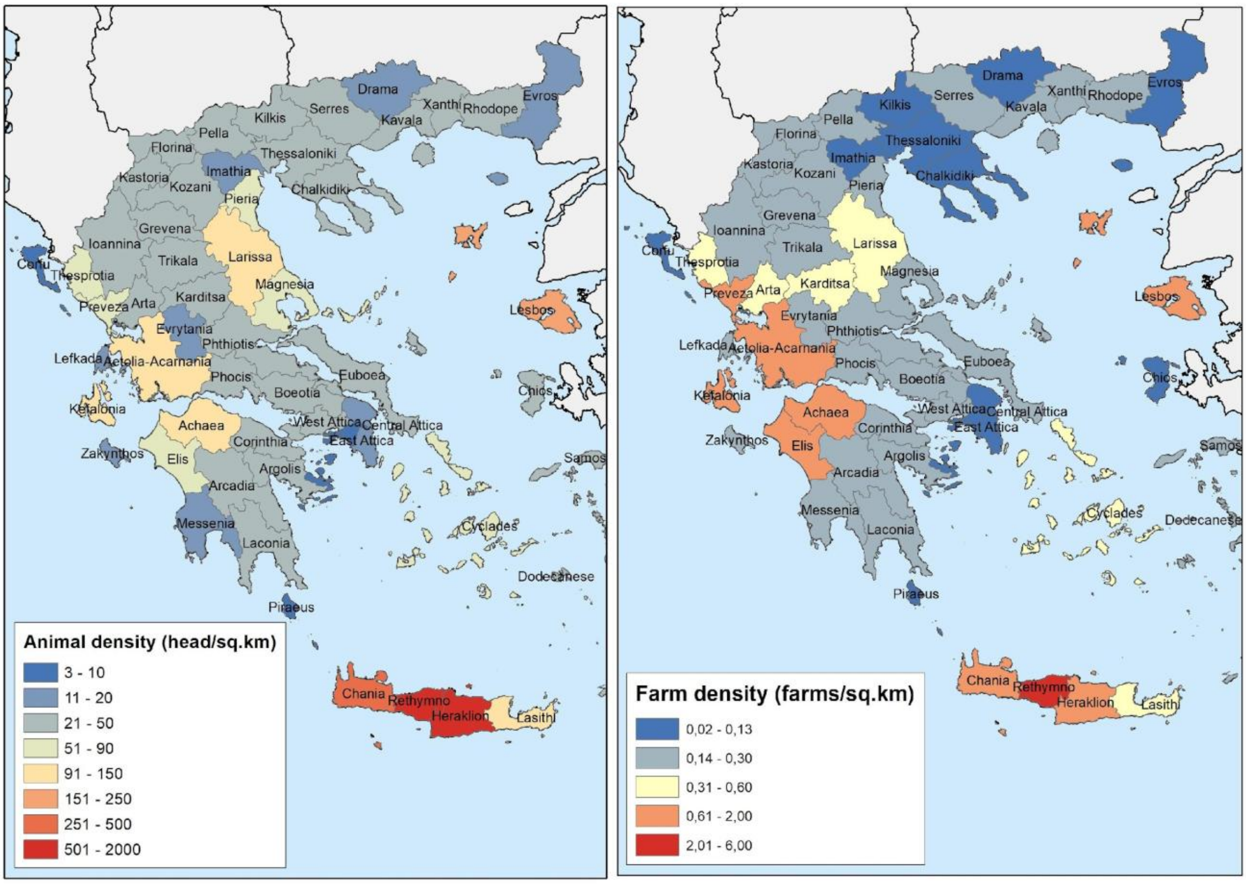

Figure 2. Animal and farm density of small ruminants in Greece

It is important to note that the scale of density values is very different in the two countries, with Greece having a much higher density of both farms and animals than Bulgaria, i.e. 129 heads and 0.64 farm per square km on average, and 13 heads and 0.22 farm per square km, respectively.

Notably, the areas with the highest density of farms and animals in Bulgaria are the southern (at the border with Greece) and eastern regions, while in Greece, apart from Crete, the most animal dense regional units are Larissa, Achaea, Aetolia-Acarnania. This should be considered when comparing the number of outbreaks in these regions (Figure 6).

The distribution of small ruminant farm size in both countries is shown in Figure 3, Figure 4 and Figure 5 below according to size class.

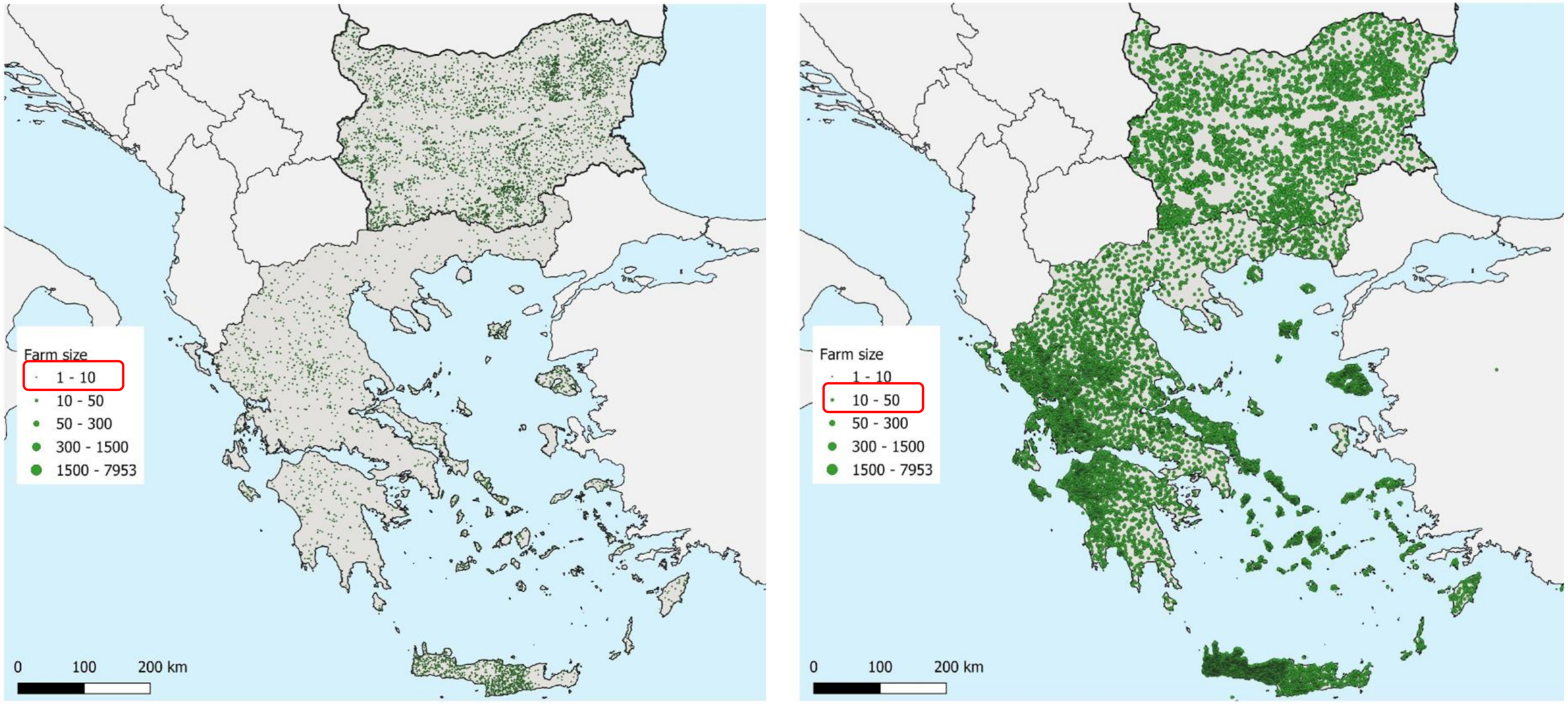

Figure 3. Distribution of small ruminant farm size (class 1-10 and 10-50 animals)[6]

[6] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence

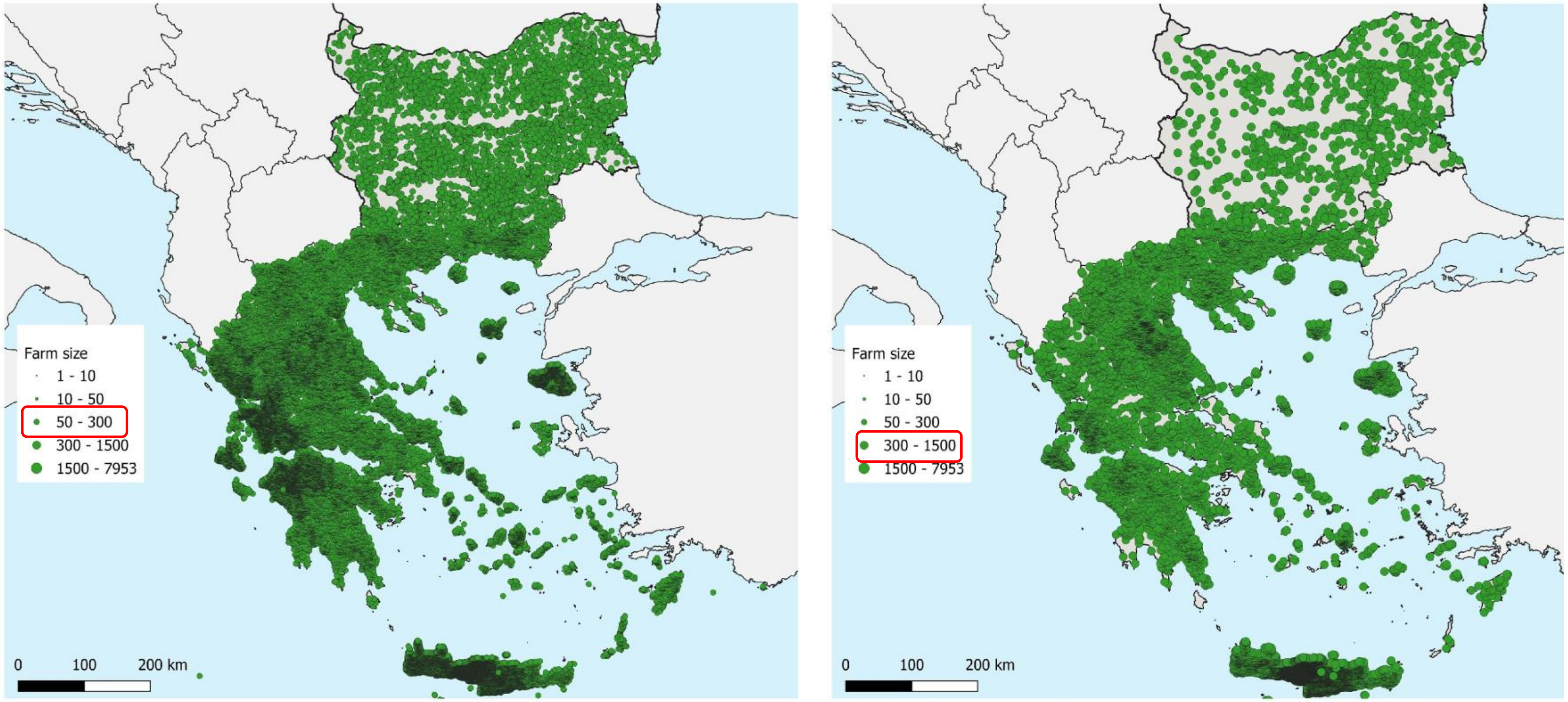

Figure 4. Distribution of small ruminant farm size (class 50-300 and 300-1500 animals)[7]

[7] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence

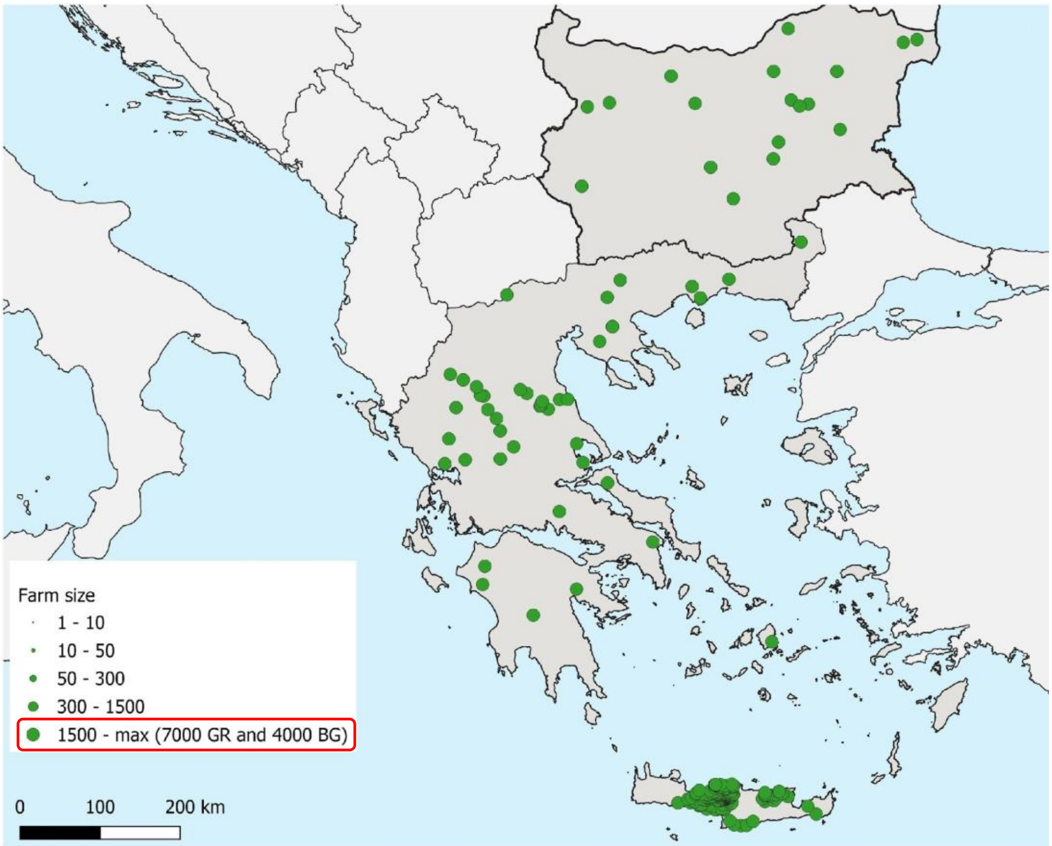

Figure 5. Distribution of small ruminant farm size (class 1500 animals-max value)[8]

To note the higher farm density in Greece, especially in the size class 50-1500 heads, in particular in the Thessaly region (Regional Units of Larissa and Magnesia) and Western Central Greece (RUs Achaea, Aetolia-Acarnania, Elis) and the island of Lesbos, which is also very close to Turkish coasts.

These high concentrations of small ruminant farms, often with large numbers of sheep per square kilometre, many small, geographically clustered holdings and frequent animal movements between farms (e.g., grazing, trading, communal pastures), together with the proximity to countries where the disease is endemic (e.g. Türkiye) greatly amplifies the risk of disease introduction and rapid spread from Türkiye.

3.2.2 Sheep and goat pox epidemics in 2024-2025 in the Balkan region

After the SGP outbreaks occurred in Greece and Bulgaria in 2013-2014 (EFSA AHAW Panel, 2014) and other sporadic re-occurrences of infection in 2017-2018 and 2023, a major epidemic occurred in these countries during the years 2024 and 2025 (Figure 6). The peak of outbreaks in both 2024 and 2025 was detected in late summer–fall, followed by an apparent reduction in the number of outbreaks during the winter.

[8] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence

During 2024, according to data reported to the Animal Disease Information System (ADIS)[9], a total of 340 outbreaks (12 in Bulgaria, 328 in Greece) were notified. A resurgence of SGP outbreaks was observed from April to September 2025, when a peak of 354 outbreaks was reported in Greece. Overall, since 1 January 2024 until 29 January 2026, 203 outbreaks of SGP were notified in Bulgaria and 2081 in Greece (Figure 6 and Figure 7).

In addition to the epidemics in Bulgaria and Greece, 27 outbreaks were notified in Romania from June 2025, and three in Serbia in (two in September and one in October 2025). Recently, on 23 January 2026, one outbreak was reported in North Macedonia (confirmed on 27 January). Collaboration between the NRLs of Greece, Bulgaria, and Romania and the EURL confirmed that the outbreaks in all countries were caused by a near identical sheep pox strain.

The geographical pattern of the spread of infection clearly indicates an East-to-West direction, with the first outbreaks occurring close to the border of Türkiye (Figure 8 and Figure 9 and dynamic spread map at this link www.zenodo.org/uploads/18439735), thus suggesting the possible introduction of infection from that country. In fact, from Figure 6 it is evident that SGP circulates endemically in Türkiye, at least since 2021 according to ADIS data. It is noteworthy that the introduction of infection and the peak of outbreaks in Bulgaria and Greece follow the peak of infection in Türkiye, where a seasonality of SGP was observed with a peak in winter (from December to February) (Şener & Türk, 2023).

In Greece, the initial spread in the region of East Macedonia and Thrace was coupled, almost immediately, with some "jumps" of the infection to Central and West Greece, possibly associated with to the movement of infected animals, with a similar pattern already observed in 2014 (EFSA AHAW Panel, 2014).

Based on the information provided by the Greek veterinary services regarding the epidemiological situation, an increase in the movement of small ruminants is observed usually during the holiday periods of Christmas, Easter, and in August, particularly in certain regional units, such as Xanthi and Komotini which may be linked to traditional religious customs/festivity[10]. Uncontrolled movements might have occurred due to long-lasting bans in place in the infected regions, above all in the regions close to borders, particularly in northern Greece, or the spread of infection linked to the shared use of pastures with neighbouring countries.

[9] https://food.ec.europa.eu/animals/animal-diseases/animal-disease-information-system-adis_en
[10] first week of June in 2025

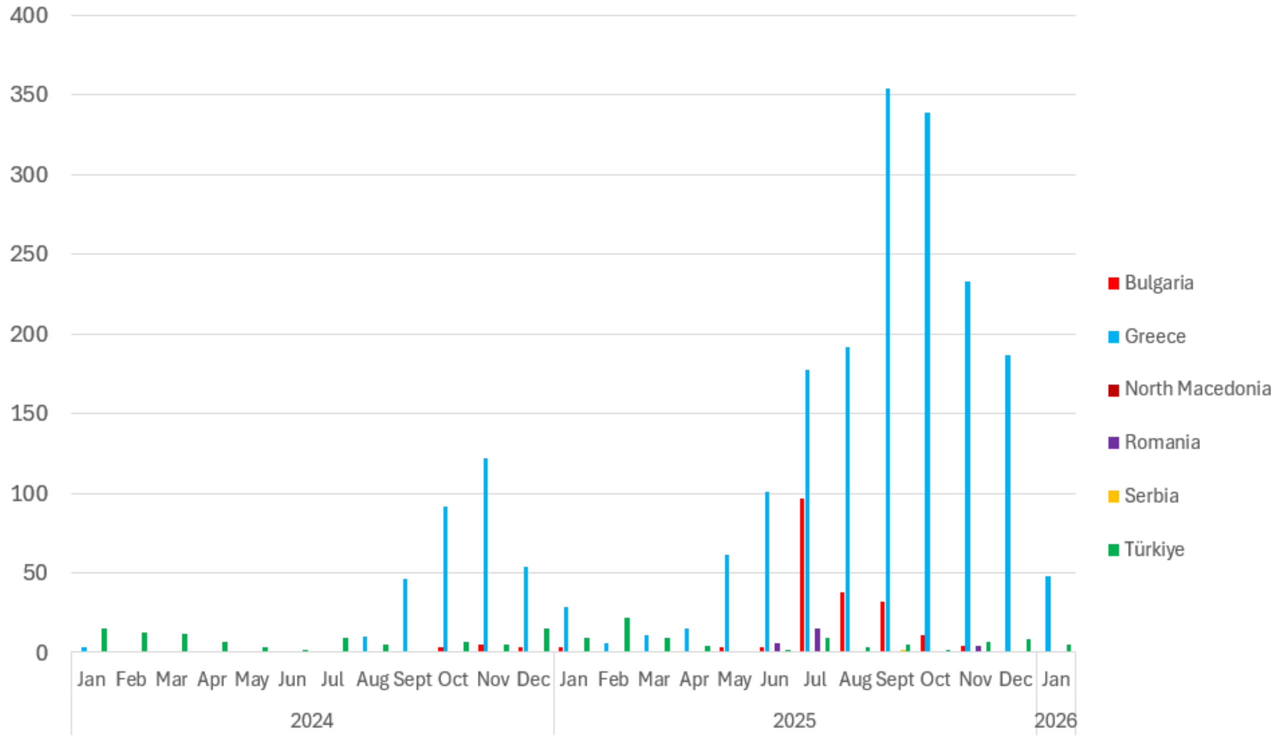

Figure 6. Number of reported outbreaks of SGP according to suspicion date as from ADIS data from 1 Jan 2024 until 29 Jan 2026.

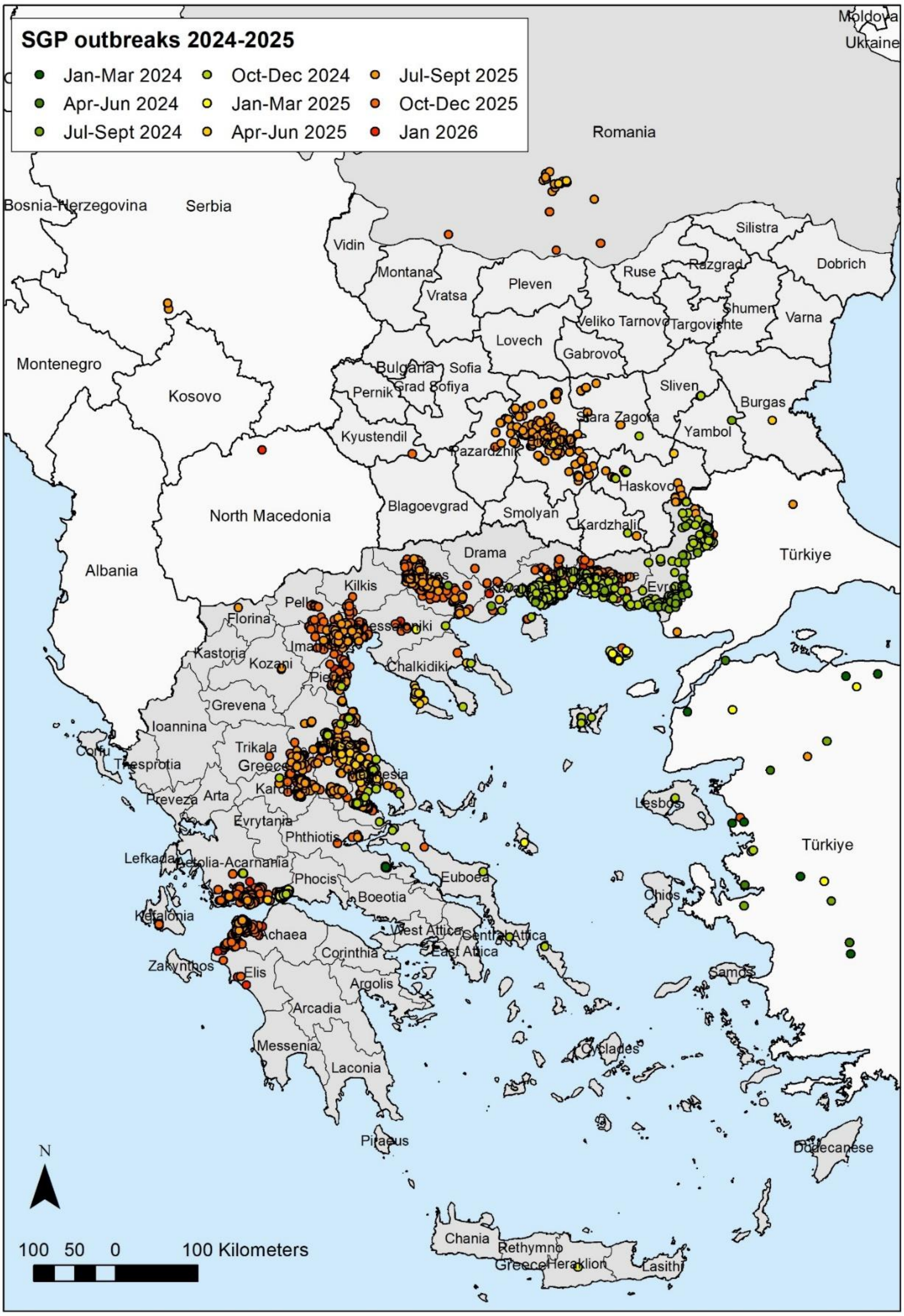

Figure 7. SGP outbreaks reported to ADIS from 1 Jan 2024 until 29 Jan 2026, grouped per trimester of suspicion date. Regions in Bulgaria and Greece are highlighted.[11]

[11] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence

Bulgaria experienced sporadic outbreaks of sheep pox in 2013 (4 outbreaks) and 2023 (1 outbreak) successfully controlled by stamping out, zoning and movement restrictions in accordance with the European legislation. Sheep pox re-emerged later with 12 outbreaks in 5 administrative regions in 2024 (6 outbreaks in Haskovo, 3 in Sliven, 1 in Stara Zagora, 1 in Yambol region and 1 in Kardzhali region) and with 191 outbreaks in 8 administrative regions in 2025, as by 5th Dec (1 in Burgas, 16 in Haskovo, 1 in Kardzhali, 1 in Kyustendil, 15 in Pazardjik, 144 in Plovdiv, 3 in Sliven and 10 in Stara Zagora region). In Bulgaria, the infection spread for around 180 km from the south-eastern border with the Greek Regional Unit of Evros to the central part of the country.

The most probable transmission pathways for the disease spread are uncontrolled movement of animals, which can occur especially during national/religious holidays (in May, June and August), shearing campaigns (end of May, June), common pastures/common watering, and mating season. Pathways for further spread which could not be ruled out could also be associated with other on-farm activities, e.g. milk collection trucks or human activities, such as family/neighbour visits. In some cases, under or late reporting of suspicions may have delayed the outbreak emergency response and the general low acceptance of the measures, particularly “stamping out”, might have reduced the collaboration of farmers, thus hampering the surveillance efficiency of official veterinary teams (information provided by Bulgarian veterinary authorities).

Measures as defined in the EU legislation and particularly Commission Delegated Regulation (EU) 2020/687 of 17 December 2019 supplementing Regulation (EU) 2016/429 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases and the complementing Commission Implementing Decisions concerning certain emergency measures relating to sheep pox and goat pox in Bulgaria, were implemented. The Bulgarian Food Safety agency timely put resources on surveillance, outbreak management, laboratory capacity, trainings, awareness campaigns and other activities in a longer-term period. Despite of the efforts and measures applied, SGP has spread across Plovdiv, Haskovo, Pazardjik and Stara Zagora regions and the measures implemented so far seem not to be sufficient for the time being to meet the objective of disease control and eradication.

Considering the constant presence of the disease in the second half of 2025, the identified gaps in biosecurity, the possible underreporting of disease suspicions, late detection and management of outbreaks in some cases, the possible illegal movements of animals, the unclear evidence for the way of virus introduction to new territories and/or establishments, the stability and persistence of the virus, the observed relatively easy spread in the already affected and newly affected areas, implementation of other measures including vaccination campaigns against SGP in the highly affected regions should be explored to supplement other control measures.

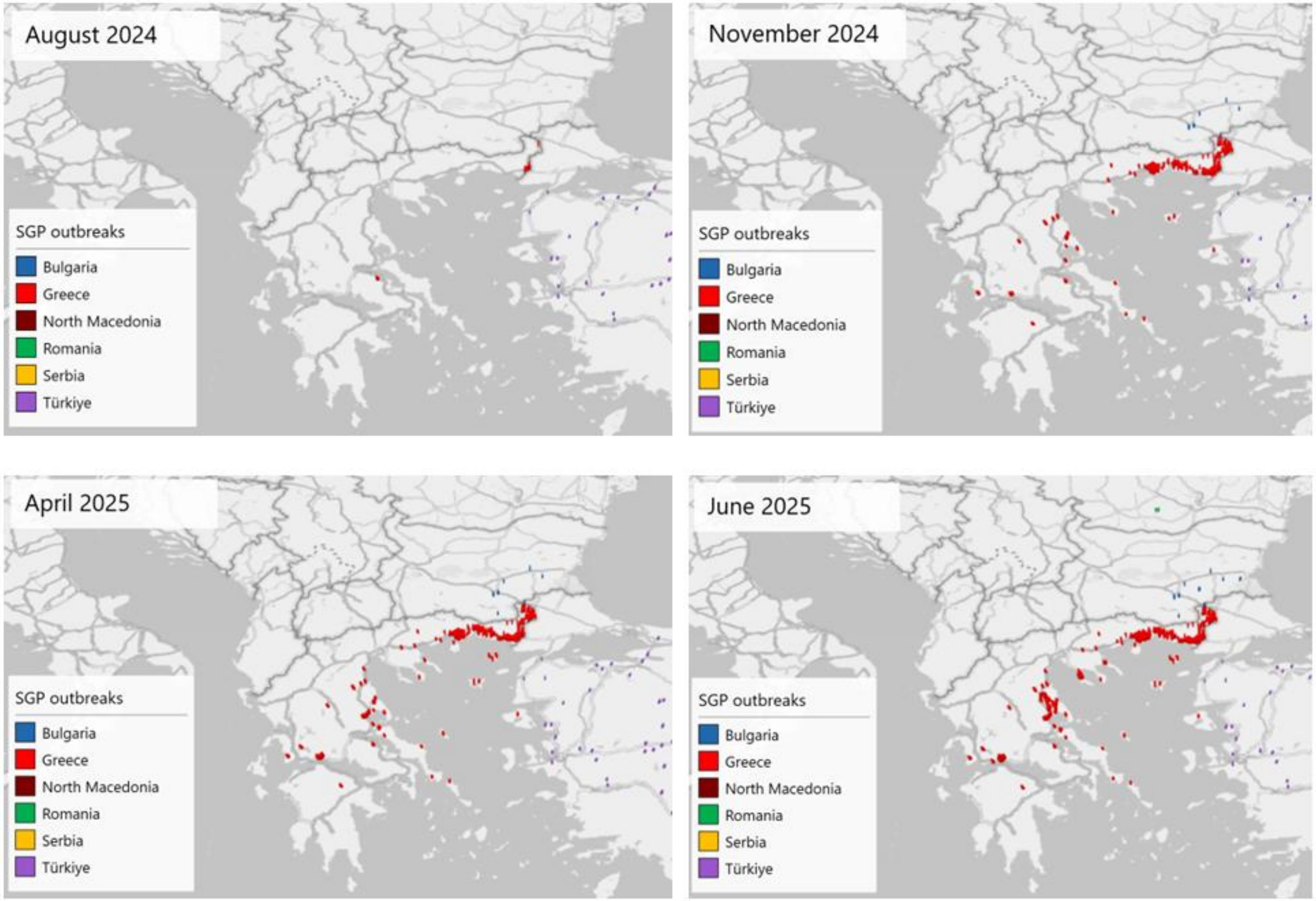

Figure 8. SGP spread maps in the Balkan region since August 2024 until June 2025, showing the progression of the outbreaks[12,13]

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[12] The dynamic spread map available at this link www.zenodo.org/records/18439735

[13] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence

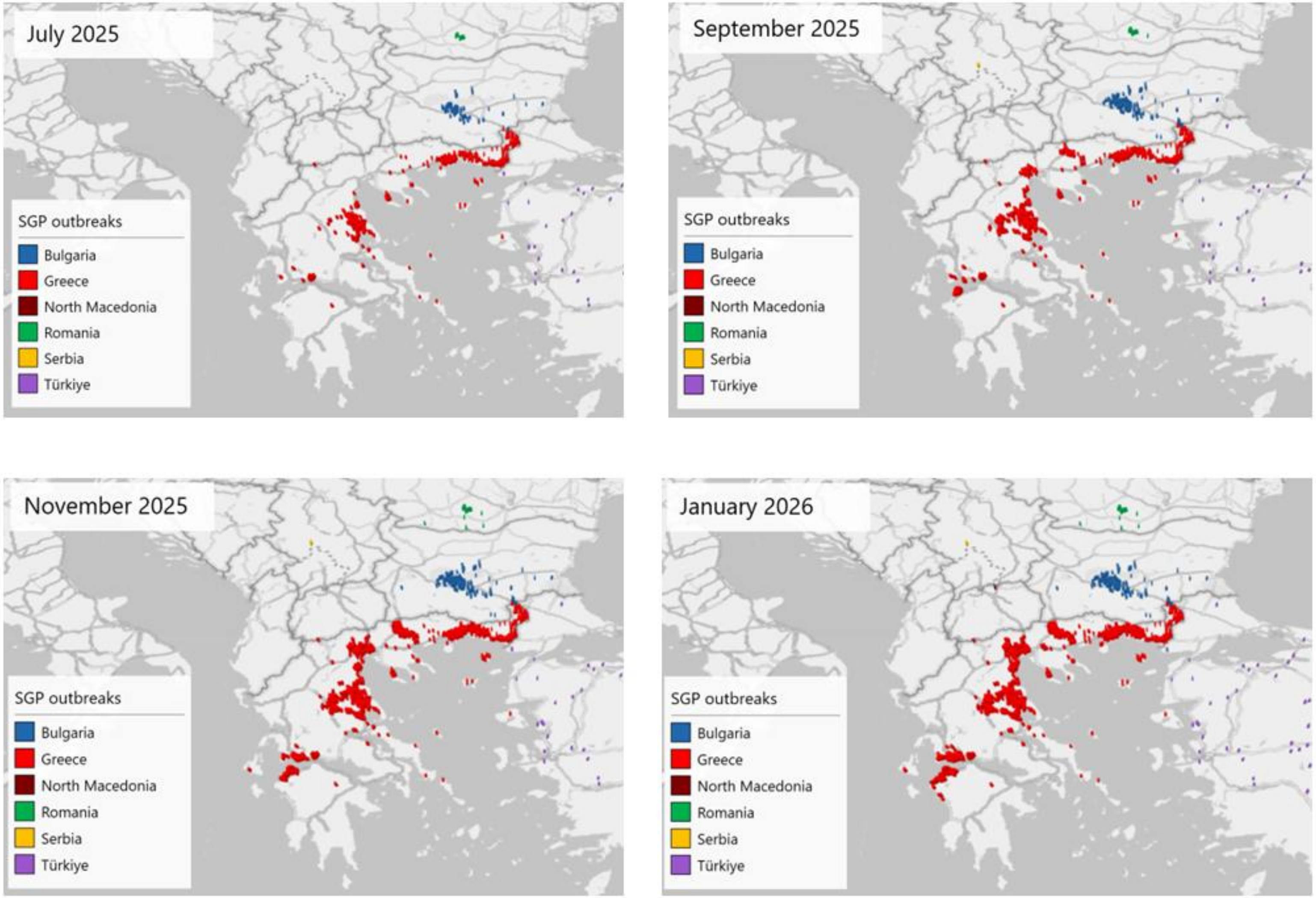

Figure 9. SGP spread maps in the Balkan region from July 2025 until November 2025, showing the progression of the outbreaks[14] [15]

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[14] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence

[15] dynamic spread map available at https://zenodo.org/records/18439735

3.2.3 Spatio-temporal clusters of SGP outbreaks in Greece and Bulgaria in 2024-2025 epidemics

An analysis of the spatio-temporal clusters was made, using ST-DBSCAN clustering function (QGIS), and considering the following parameters and relative reasoning for their choice:

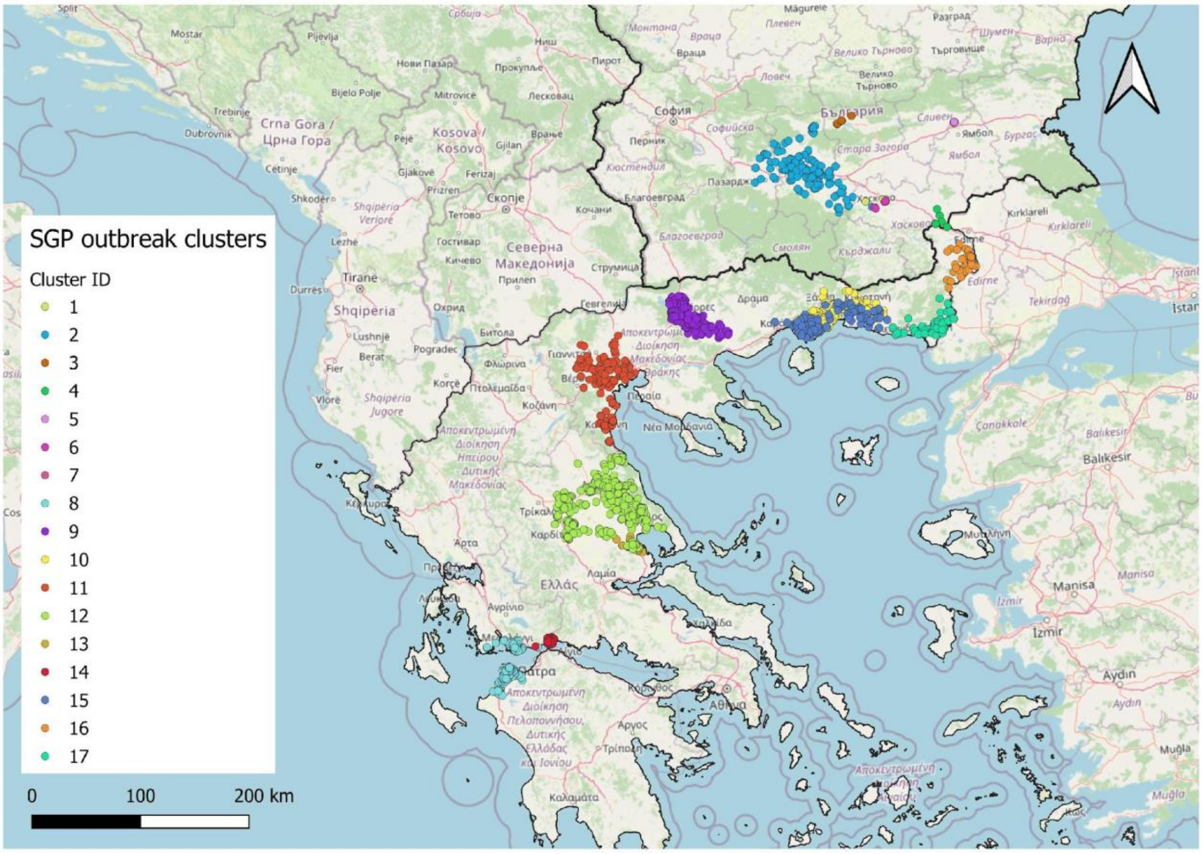
- maximum time duration between clustered points = 28 days, considering the incubation period of 7-14 days + time lag to detect the disease;
- maximum distance between clustered points = 20 kilometres, which is the surveillance area, considering a period of 28 days to detect the disease;
- Greece: minimum cluster size = 25 points, while Bulgaria and Romania: minimum cluster size = 5 points, since the ratio between the outbreaks in Bulgaria and Greece is about 1 to 5.

Table 3 shows the results of the cluster analysis, which identified 10 spatio-temporal clusters in Greece, 6 in Bulgaria and 1 single cluster in Romania.

Table 3. Identified clusters of SGP epidemics in 2024-25 in Greece, Bulgaria and Romania

Country	Cluster id.	Number of points
Bulgaria	1	5
	2	156
	3	8
	4	6
	5	6
	6	5
Romania	7	22
Greece	8	239
	9	160
	10	238
	11	143
	12	382
	13	41
	14	79
	15	147
	16	38
	17	69

The map in Figure 10 shows the geographical representation of epidemic clusters.

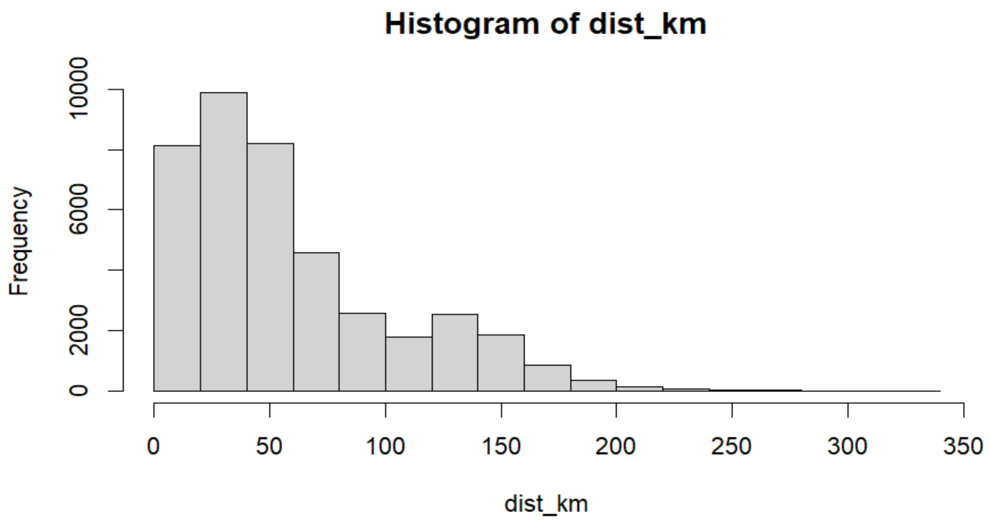


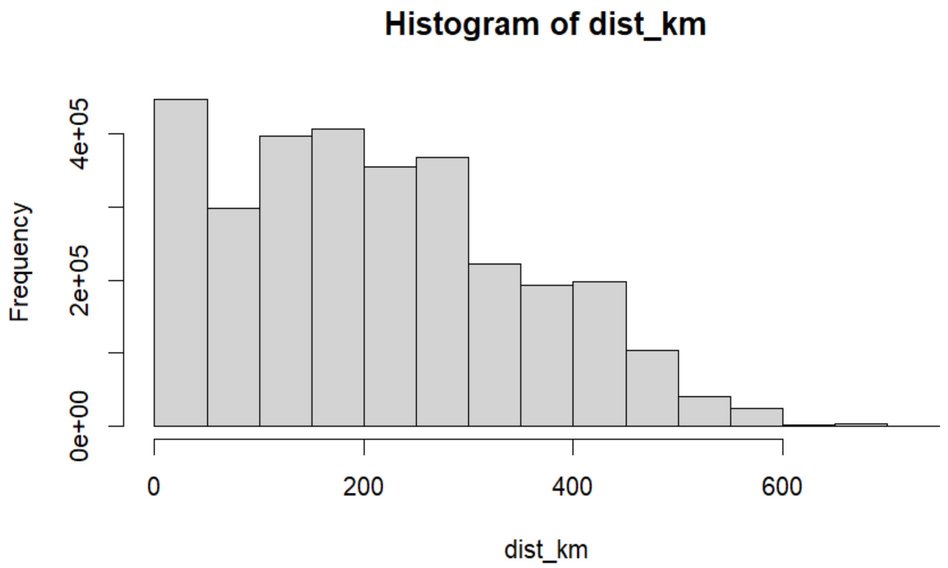
Map data: © OpenStreetMap contributors, QGIS

Figure 10. Map showing the results of the cluster analysis of SGP epidemics in Greece, Bulgaria and Romania (Cluster ID as in Table 1)[16]

The analysis of the distances among outbreaks, also, indicated a rather concentration of infection in Bulgaria, and the wide extension on Greece (Figure 11).

[16] Any designation of Kosovo is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Court of Justice Opinion on the Kosovo Declaration of Independence





Graph above, Bulgaria (Min: 0.0; 1st Qu: 24.13; Median: 45.24; Mean: 58.57; 3rd Qu.: 79.65; Max.: 327.43); graph below, Greece (Min: 0.0; 1st Qu: 103.2; Median: 197.1; Mean: 212.3; 3rd Qu.: 303.7; Max.: 740.1.

Figure 11. Frequency histogram of distance between SGP outbreaks in Bulgaria and Greece

These results confirm the hypothesis of a single incursion in Bulgaria and Romania, whereas in Greece multiple foci of infections occurred, through introduction of infected animals or movement of undetected infected animals at long distance, which triggered new spread clusters (Figure 10).

In Greece the presence of 4 clusters very distant from each other and across the country with the distance median of 200 km suggests that there has been long-distance movement of infected animals, and/or possibly some delays in reporting of new introduction that has masked the identification of shorter-range outbreaks along the movement routes.

3.3 Vaccination scenarios

3.3.1 Vaccination in surveillance zones

As a baseline approach, considering a buffer zone of 10 or 20 km (in the revised Reg. 687/2020 the surveillance zone for SGP is extended from 10 to 20 km), around each outbreak reported up to 10th Dec 2025, the farms and animals that can be vaccinated in the surveillance zones are shown in Table 4 and the area and regions initially planned (up to mid November 2025) to be included in the vaccination are shown in Figure 12.

Table 4. Farms and animals to be vaccinated in Greece and Bulgaria considering 10 or 20 km ring around each reported outbreak.

	Bulgaria		Greece	
	farms	animals	farms	animals
Total population	24,300	1,430,000*	83,500	17,000,000**
Small ruminant population in 10 km surveillance zone	2,500	192,000	16,000	3,000,000
Small ruminant population in 20 km surveillance zone	5,000	370,000	30,000	5,600,000

*1.23 million sheep and 200 thousand goats

**13 million sheep and 4 million goats

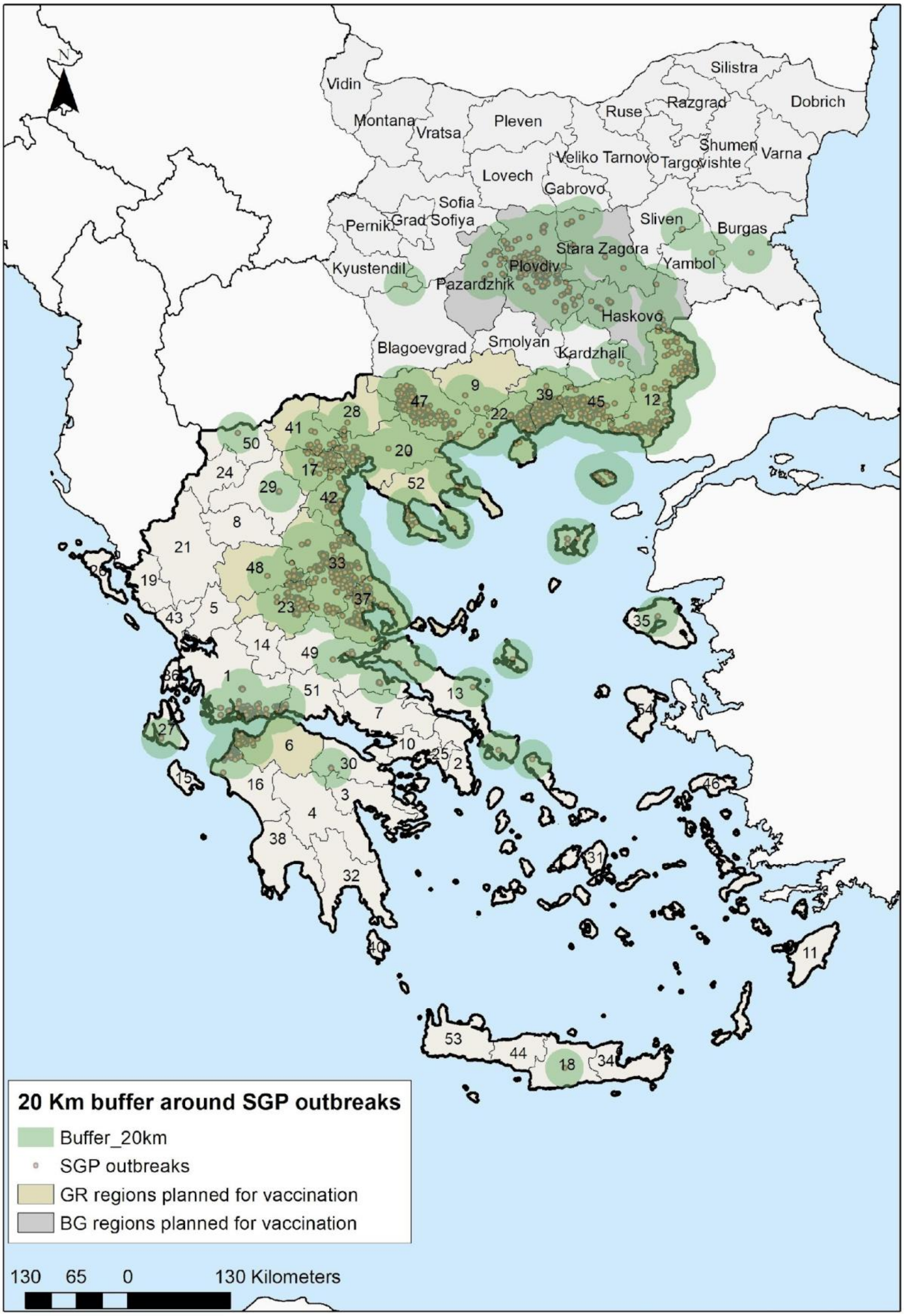


Figure 12. Buffer zone of 20 km radius around SGP outbreaks reported in Greece and Bulgaria until 10th December 2025, and regions highlighted that were to be included in vaccination plans (for names of Regional Units in Greece refer to Table 6).

The Bulgarian authorities planned to include the total small ruminant population of the four most SGP affected regions in the vaccination campaign as shown in Table 5. It can be noted that the numbers are very similar as for the 20 km ring vaccination as in Table 4.

Table 5. Total farms and animals in the four most affected Bulgarian regions, to be included in the vaccination plans

Region	Estimated number of small ruminant farms to be included in vaccination plans	Estimated number of small ruminants to be included in vaccination plans
Plovdiv	881	90300
Haskovo	1864	86162
Stara Zagora	741	37360
Pazardzhik	592	45131
Total	**4078**	**258953**

For Greece it is interesting to compare the number and proportion of farms and animals in the surveillance zones in each regional unit with the total number (Table 6).

Table 6. Total number of small ruminant population in each regional unit in Greece and number of holdings and animals in the surveillance zones (in bold the regional units initially planned for vaccination, as Figure 11).

Region ID	Regional Units	Total number of farms	Total number of animals	No. of farms in the 20km surveillance zones and % of the total population		No. of animals in the 20km surveillance zones and % of the total population	
6	**Achaea**	**3,555**	**558,027**	**1,785**	**50%**	**266,197**	**48%**
1	Aetolia-Acarnania	7,415	1,091,884	3,529	48%	500,642	46%
4	Arcadia	1,306	227,402	50	4%	9,518	4%
3	Argolis	690	123,737	101	15%	18,416	15%
5	Arta	1,057	112,424				
7	Boeotia	731	132,668	72	10%	9,973	8%
25	Central Attica	14	1,725				
52	**Chalkidiki**	**466**	**141,232**	**270**	**58%**	**70,777**	**50%**
53	Chania	5,686	922,364				
54	Chios	141	39,578				
26	Corfu	56	5,635				
30	Corinthia	708	103,890	353	50%	44,811	43%
31	Cyclades	2,351	241,556	299	13%	30,416	13%
11	Dodecanese	1,116	128,298				
9	**Drama**	**494**	**113,802**	**322**	**65%**	**74,011**	**65%**
2	East Attica	242	47,786				
16	Elis	2,770	372,585	840	30%	107,267	29%
13	Euboea	2,021	234,993	1,318	65%	153,443	65%
12	**Evros**	**879**	**111,455**	**879**	**100%**	**111,455**	**100%**
14	Evrytania	451	41,245				

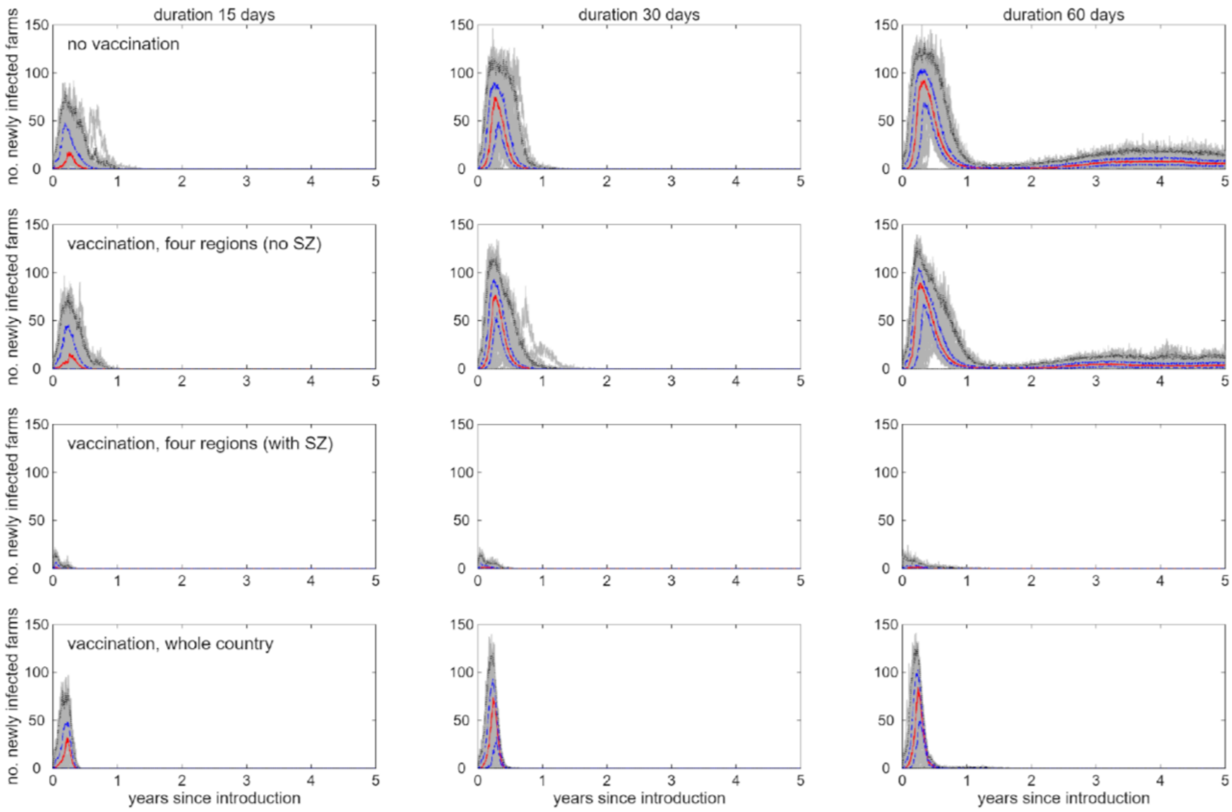
50	Florina	614	111,786	277	45%	48,703	44%
8	Grevena	607	106,224	1		160	
18	Heraklion	7,343	2,076,143	3,794	52%	1,024,852	49%
17	**Imathia**	**278**	**43,262**	**258**	**93%**	**40,366**	**93%**
21	Ioannina	1,750	206,157				
23	**Karditsa**	**1,597**	**192,697**	**1,309**	**82%**	**157,291**	**82%**
24	Kastoria	405	75,630	10	2%	2,136	3%
22	**Kavala**	**585**	**122,602**	**578**	**99%**	**121,250**	**99%**
27	Kefalonia	1,022	208,608	782	77%	161,290	77%
28	**Kilkis**	**542**	**137,165**	**309**	**57%**	**78,054**	**57%**
29	Kozani	1,111	248,245	397	36%	89,275	36%
32	Laconia	1,033	215,853				
33	**Larissa**	**3,292**	**955,654**	**2,863**	**87%**	**779,660**	**82%**
34	Lasithi	1,261	348,358				
36	Lefkada	108	9,844				
35	Lesbos	3,697	560,906	2,647	72%	413,659	74%
37	**Magnesia**	**1,069**	**227,447**	**958**	**90%**	**203,179**	**89%**
38	Messenia	810	91,485				
41	**Pella**	**607**	**128,642**	**349**	**57%**	**77,224**	**60%**
51	Phocis	652	88,463	177	27%	16,772	19%
49	Phthiotis	1,472	196,347	805	55%	95,500	49%
42	**Pieria**	**710**	**143,546**	**707**	**100%**	**142,834**	**100%**
40	Piraeus	104	9,099				
43	Preveza	1,110	142,314				
44	Rethymno	12,573	4,392,719	10		6,275	
45	**Rhodope**	**942**	**128,752**	**936**	**99%**	**128,004**	**99%**
46	Samos	328	29,318				
47	**Serres**	**1,172**	**251,153**	**1,138**	**97%**	**245,736**	**98%**
19	Thesprotia	1,092	141,098				
20	**Thessaloniki**	**793**	**206,126**	**715**	**90%**	**184,198**	**89%**
48	**Trikala**	**1,664**	**244,841**	**902**	**54%**	**133,066**	**54%**
10	WestAttica	241	40,311	14	6%	2,998	7%
39	**Xanthi**	**660**	**67,724**	**638**	**97%**	**63,775**	**94%**
15	Zakynthos	188	9,483				
TOTAL		**83,581**	**16,910,288**	**30,392**	**36%**	**5,613,183**	**33%**

Compared to the initial plan indicated by the authorities in November 2025, further outbreaks have been reported up to 10 December, therefore there are further regional units in Table 6 that entail consistent population fractions in the surveillance zones. The small ruminant population in the affected regions up to 17th December is approximately 54,000 farms and 9.9 million animals. If a threshold of 10% of small ruminants in the surveillance zones of the total population in each regional unit is considered, the total number of farms and animals to be vaccinated would be 30,235 and 5,582,123, respectively.

3.3.2 Vaccination scenarios based on spread model: Bulgaria

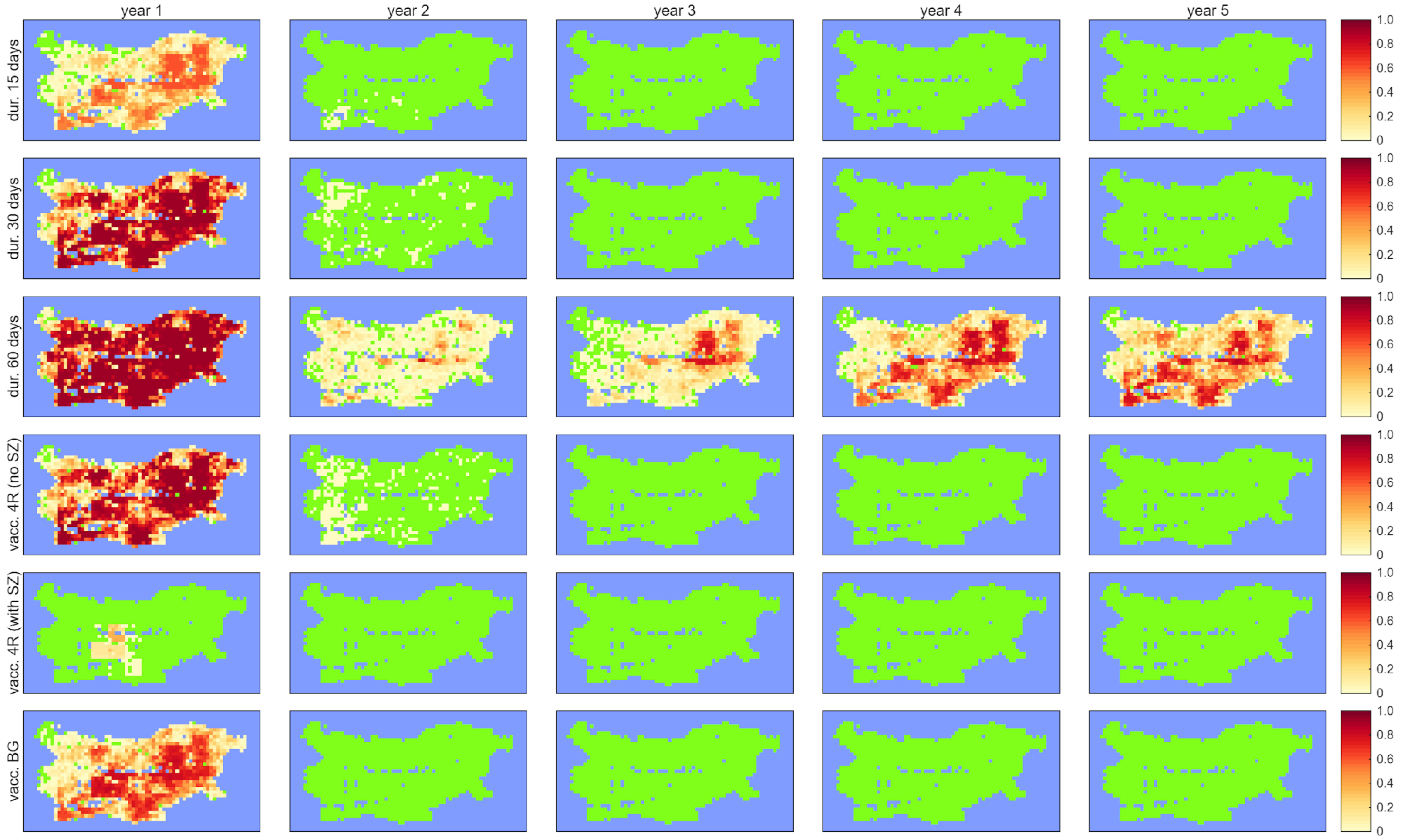
In the absence of control, the model predicted that SGP is likely to spread throughout Bulgaria and become endemic (Figure 13 and Figure 14). Provided infected farms are detected and culled sufficiently rapidly (within around 30 days, i.e. 2-3 incubation periods (25 days) and the time from reporting to culling (5 days)) applying culling of infected farms brought epidemics under control within 1-2 years (Figure 13 and Figure 14).

Nationwide vaccination was predicted to reduce spread in terms of both the number of infected farms (Figure 13) and the extent of spread (Figure 14). If vaccination was used only in four regions (i.e. those close the site of the original incursion, Plovdiv, Haskovo, Stara Zagora, Pazardzhik), the model suggested there is a risk that the virus will escape the vaccinated region and spread more widely, but this can be mitigated if strict movement restrictions within the surveillance zones (20 km) are applied in the vaccinated region, modelled as no transmission occurring beyond 20 km of an infected farm. Vaccinating the whole country also was also predicted to mitigate this risk of virus escape and resulted in less spread than normal detection and culling alone.



Legend: Columns differ in the assumed duration of an outbreak on an infected farm: 15 days, rapid detection and culling (left); 30 days, normal detection and culling (middle); or 60 days, no control (right). Rows differ in terms of vaccination strategy: no vaccination (first row); annual vaccination in four regions (Plovdiv, Haskovo, Stara Zagora and Pazardzhik) for five years (second row); annual vaccination in four regions for five years with strict movement restrictions (so no transmission beyond 20 km of an infected farm) (third row); and annual vaccination of the whole country for five years (fourth row). Each plot shows the individual replicates (grey lines) and the median (red line), 25th and 75th percentiles (blue dashed lines) and 2.5th and 97.5th percentiles (black dotted lines) for 100 replicates of the model for an incursion to a randomly selected farm in the Plovdiv region.

Figure 13. Time course of simulated epidemics of SGP in Bulgaria for different control scenarios.



Legend: The first three rows show spread with only current EU measures (rapid detection and culling, normal detection and culling, no culling). The fourth and fifth rows show spread with vaccination in four regions (without and with spread contained in a 20 km SZ) The sixth row shows spread with vaccination in whole country. Vaccination strategies assumed normal detection and culling of outbreaks was also implemented. Each map shows the proportion or simulations (out of 100) for which at least one farm in a 0.1° by 0.1° grid square became infected (indicated by the colour bar). Green squares were never infected, and blue squares contain no farms with sheep or goats

Figure 14. Simulated spatial spread of SGP in Bulgaria.

Provided normal detection and culling of infected farms was also implemented, a vaccination campaign that lasted two years was predicted to be sufficient to eliminate SGP in Bulgaria (Figure 14). Moreover, the time to elimination was one year shorter with vaccination compared to without vaccination. If vaccination was implemented only in the four initially affected regions, this needed to be accompanied by strict implementation of movement restrictions. Otherwise, virus could escape from the vaccinated region and, hence, spread more freely (cf. Figure 14). If no additional control measures were used, vaccination was predicted to be essential for bringing the epidemic under control (Figure 15). In addition, it required a vaccination campaign of at least three years duration to reliably eliminate SGP and took 2-3 years to achieve elimination.

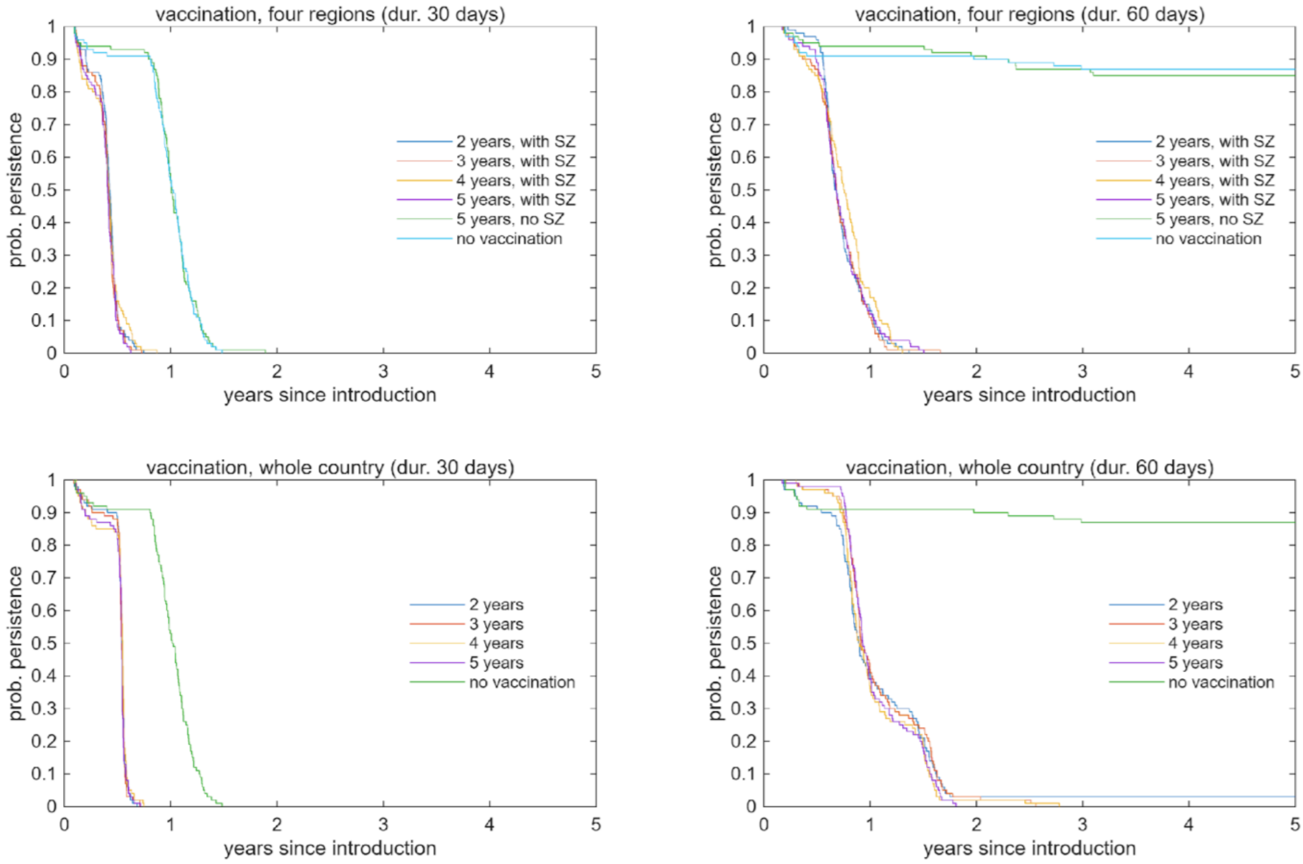


Figure 15. Simulated time to elimination of SGP in Bulgaria for different durations of a vaccination campaign.

3.3.3 Vaccination scenarios: Greece

Preliminary modelling results for Greece highlighted several challenges affecting the reliability of kernel-based epidemic simulations. As shown in Figure 10, the spatial distribution of outbreaks is characterized by multiple clusters exhibiting inconsistent temporal and spatial patterns, which complicates the estimation of a robust transmission kernel. Furthermore, the country's complex geography—dominated by mountainous regions and numerous islands—reduces the suitability of simple distance-based kernels, as these do not adequately take into consideration the natural barriers to disease spread. For these reasons the kernel-based model may not accurately represent national epidemic dynamics and is therefore of limited value for evaluating vaccination strategies

Model simulation outputs reflected these limitations. Outbreaks displayed irregular behaviour, with some simulated epidemics failing to propagate, while others expanded rapidly upon reaching areas of high host density. Notably, Crete appeared disproportionately affected in many simulations, an artifact arising from the kernel's inability to account for geographic discontinuities and the high density of animals and farms on the island.

A more realistic modelling approach may require seeding infections according to observed outbreak locations rather than relying solely on kernel-driven spread. However, technical issues within the current modelling framework must be resolved before such refinements can be implemented, which is not possible within the time frame available for this work.

From the descriptive spatio-temporal analysis, two important aspects of the SGP epidemics in Greece should be noted: i) the extensive geographical and temporal scale of SGP epidemics in Greece and ii) the multiple epidemic clusters, possibly due to long distance animal movements. This suggests that additional control measures (e.g. vaccination) should be added to what currently in place. Based on the epidemiological evidence, a nationwide vaccination campaign should be considered, prioritising the already affected regions, which comprise roughly 9.9 million animals and 54,000 farms. Moreover, it can be considered that vaccination efforts should initially prioritise the western regions to halt the advancing disease front, preserving those areas not affected yet. Under this prioritization scenario, around 4.4 million or 2.5 million of heads should be vaccinated in the western most areas, in case vaccination of animals in the whole region or in the 20 km surveillance zones is applied respectively.

The criteria for the prioritisation of vaccination activities should consider not only the currently affected areas but also the existence of possible movement patterns of the animals that should be assured, like those toward summer pastures, which cannot be completely banned for welfare reasons.

Finally, considering the reported outbreaks in Romania, Serbia and in Greece close to the border to North Macedonia, nation-wide campaign of preventive vaccination against SGP may be taken into consideration in those countries before the next season.

4 Conclusions and recommendations

Epidemiological situation

1. SGP evolved into a major regional epidemic in 2024–2026, with Greece and Bulgaria experiencing unprecedented outbreak numbers and Romania and Serbia reporting new cases, indicating expanding geographic spread.

2. The epidemiological pattern strongly suggests introduction and seasonal spillover from Türkiye, where SGP circulates endemically, followed by rapid East-to-West spread driven largely by animal movements.

3. The wide geographic spread and repeated emergence of new clusters of infection in Greece indicate either ongoing long-distance transmission and possible underreporting, or multiple independent seeding events, allowing new epidemics to ignite in distant regions and expand before effective control is established. On the other hand, Romania and Bulgaria likely experienced single introductions of the virus.

4. Animal movement— both authorized and uncontrolled—along with cultural practices, shared pastures, and on-farm activities played a major role in accelerating transmission, while delayed reporting and low acceptance of control measures further hindered containment.

5. Despite the EU mandated control measures, the disease continued to spread, revealing gaps in their implementation, in biosecurity and outbreak management; therefore, additional interventions such as targeted vaccination campaigns should be considered to support eradication efforts.

6. In Greece especially, but also in Bulgaria, the combination of dense small-ruminant populations, interconnected production systems, and proximity to a country where certain livestock infectious diseases are endemic (i.e. Türkiye) creates a highly favourable environment for pathogen incursion, establishment and transmission. This elevated and region-specific epidemiological risk may justify the need for quickly implementable ad hoc targeted prevention and control measures.

Vaccines:

7. From the literature screening, live attenuated and combination/bivalent vaccines demonstrate the highest and most consistent protection on sheep and goats, with efficacy commonly reaching 80–100%, while inactivated vaccines can also achieve full protection when administered at high doses and/or after booster.

8. Commercially available live attenuated SGP strains are generally safe. Safety profiles may vary by certain experimental vaccine strains, the animal species and breed, and dose administered: commercial live-attenuated vaccines are generally safe when administered according to the manufacturer's recommendations, but overdosing or stress can lead to reproductive issues, highlighting the need for strict adherence to recommended dosing and routine monitoring. Preliminary vaccination trials could be performed to show suitability in the local context.

9. Inactivated vaccines may offer improved safety but are not commercially available and have the practical limitation of inducing short term immunity, thus the need of frequent boosters.

9. In the experiments conducted by EURL for *Capripoxviruses*, all three sheep pox vaccine strains tested (RM-65, Romania, Bakirköy) effectively (100%) prevented mortality, strongly reduced morbidity (79-100%), and strongly reduced viral replication and shedding, with vaccinated sheep showing dramatically lower viremia and nasal viral loads compared to non-vaccinated controls.

10. Safety and efficacy profiles differ among vaccines: RM-65 and Romania strain-based vaccines fully protect against morbidity but may cause fever or lesions after vaccination, while the Bakirköy strain-based vaccines offer strong protection with fewer and milder side effects, making it the safest option overall.

11. Risk of vaccine virus transmission was judged very low and could be further reduced by avoiding contact with unvaccinated animals up to three weeks post-vaccination, the time necessary to develop the protective immune response.

12. The risk of vaccine virus transmission is minimal, and given their strong protective performance, these vaccines represent reliable tools for controlling sheep pox under field conditions.

Vaccination scenarios

13. Based on the spread model applied in Bulgaria, rapid detection and culling of infected farms— if conducted systematically within approximately 30 days after virus introduction into a flock—was sufficient to bring epidemics under control within 1–2 years.

14. Nationwide vaccination significantly reduced both the number of infected farms and the geographic extent of spread compared with detection and culling alone.

15. When vaccination is restricted to only the four initially affected regions, the model shows that there may be still a risk of viral escape, unless strict 20-km movement controls within surveillance zones were rigorously enforced. This risk is reduced by a nationwide vaccination, which further reduced the likelihood of viral escape and achieved better containment outcomes.

16. A two-year vaccination campaign, when combined with standard detection and culling, was predicted to eliminate SGP from Bulgaria, achieving eradication one year sooner than strategies without vaccination.

17. In scenarios lacking additional control measures, vaccination became essential for epidemic control, with at least a three-year campaign required for reliable elimination.

18. Under vaccination-only strategies, elimination was projected to take 2–3 years, highlighting the importance of combining vaccination with other control measures (early detection, rapid culling, and strict movement restrictions) for optimal outcomes.

19. With a likely single incursion, modelling suggests control is achievable with strong measures and vaccination.

20. In Greece, the extensive geographical and temporal scale of SGP epidemics and the multiple epidemic clusters, possibly due to long distance animal movements, suggest that additional control measures should be considered. This should be vaccination prioritising the already affected regions and even considering a nationwide vaccination campaign.

21. Given the larger geographical scale of SGP epidemics compared to Bulgaria, the conclusions indicated above for Bulgaria regarding extension and duration of vaccination campaign and effect

of additional control measures would also apply as minimum requirement to the situation in Greece.

22. In bordering countries, such as Romania, North Macedonia, Albania, Serbia, there is high risk of future outbreaks (one outbreak already reported in North Macedonia in January 2026), which may justify the evaluation of the usefulness of preventive vaccination campaigns.

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6 Annex

- Annex 1: extensive literature on vaccine effectiveness (www.zenodo.org/uploads/18439931)
- Annex 2: extensive literature on vaccine safety (www.zenodo.org/uploads/18374862)