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Moving niche agroecological initiatives to the mainstream: A case-study of sheep-vineyard integration in California

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ABSTRACT

Across the world, an increasing number of farmers are piloting agroecological systems. The recoupling of crops and livestock is one type of agroecological practice that has potential to help reduce the use of off-farm inputs, improve soil quality, and reduce costs for farmers. Yet, a major part of the world's agricultural landscapes remain dominated by conventional specialized crop and livestock practices. In particular, grazing animals in perennial cropping systems may reduce pesticide and fuel use, decrease labor, and build soil organic carbon and soil fertility. In this study, we examined adopters and non-adopters' perceptions of a niche system, integrated sheep-vineyard systems (ISVS) in California. We aimed at understanding the conditions under which ISVS, a specific case of ICLS (integrated crop-livestock systems), could be mainstreamed. We then contextualized these interviews using the Multi-Level Perspective framework to analyze the levers favoring or impeding mainstreaming of this niche system. We considered both pull factors arising from changes in the landscape, and push factors arising through decentralized, grassroot processes. Our inductive analysis is a promising first insight into farmers' perceptions and motivations toward ISVS adoption in California, considering both vineyard managers and contractors (i.e. shepherds renting their sheep to vineyard managers). We found a positive perception of ISVS among both current adopters and non-adopters regarding the potential agronomic, environmental and economic benefits of these practices. All adopters were satisfied with this system as they experienced labor and fuel savings, soil quality improvement and marketing advantages. Local push factors (bottom-up levers emerging from the niche systems) were highlighted by interviewees as contributing to adoption. Push factors identified include knowledge exchange and networking between vineyard managers and developing marketing pathways for "carbon-positive" wool, meat and wine products. However, some pull factors (macro-economic and policy levers acting as top-down levers) could help move the system beyond limited adoption. We point out biotechnical and socio-economic research avenues to encourage the scaling-up of ISVS and ICLS more broadly. On the biotechnical dimension, we recommend continuing and scaling-out system experiments to redesign vineyards considering sheep integration and evaluate the effect of grazing on soil quality and fire management. On the socio-economic dimension, we encourage the exploration of relevant spatial scenarios through co-design of collaborative arrangements between vineyard managers and contractors at the landscape level. Greater research on the social, environmental and economic services provided by ISVS is urgently needed to inform state and federal agricultural policies, including whether such systems should be supported through payment for ecosystem services and as part of environmental good practices and fire safety recommendations.

1. Introduction

The recoupling of crop and livestock systems is seen as an alternative to specialized agricultural production to improve the recycling of nutrients in food and fiber production systems, minimize losses to the environment, and reduce external inputs (Garrett et al., 2017;

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Hendrickson et al., 2008). Crop-livestock integration systems (ICLS) can also help decrease input costs and reduce risks to price or weather shocks through diversification (Franzluebbers et al., 2014; Garrett et al., 2017; Niles et al., 2018). Case-study analyses of commercial ICLS have already shown the economic and environmental benefits for cattle-crop integration in Brazil (dos Reis et al., 2021, 2020; Gil et al., 2018), the United States (Franzluebbers and Stuedemann, 2014; Hendrickson et al., 2008) and Europe (Ryschawy et al., 2013; Veysset et al., 2014). In particular, grazing animals in crop systems may reduce pesticide and fuel use, decrease labor, and improve soil organic carbon (Brewer and Gaudin, 2020; Franzluebbers, 2005; Niles et al., 2018; Ryschawy et al., 2012) without reducing yields of the main cash crop (Peterson et al., 2020).

Despite such proven advantages, most of the world's agricultural landscapes remain dominated by conventional specialized crop and livestock practices (Garrett et al., 2020). Thus far, few attempts have been made to understand why farmers do not maintain or re-adopt ICLS. Low adoption or even decline of ICLS in some parts of the world, such as Europe, can be partly explained by an increasing lack of agricultural workforce, management complexity and public policies and advising systems encouraging specialization (Lemaire et al., 2014; Ryschawy et al., 2013). While structural changes increasing the profitability of specialized systems globally explain much of the shift away from integrated systems (Garrett et al., 2020), the decision of whether to adopt more diverse integrated systems involves unique internal and external utility tradeoffs beyond farm income maximization (Gil et al., 2016). The motivations and perspectives of farmers vis-à-vis integrated systems need to be understood if their redevelopment is to be fostered (Cortner et al., 2019). Yet we lack such analysis of farmers' perceptions for specific cases of ICLS and in different socio-ecological landscapes.

Farmer behavior is influenced by both objective conditions (e.g. benefits and constraints to adopting a practice or a system) and perceptions of these conditions, which are both internal, e.g. individual to the farmer, such as attitudes and beliefs (Ajzen, 1991; Cortner et al., 2019; Schill et al., 2019) or external factors, such as policies and market systems (Reimer et al., 2012; Rodríguez-Cruz and Niles, 2021). A farmer's net benefits of adopting or retiring an agricultural practice, therefore, may depend on the farmer's behavioral objectives, portfolio of assets, existing practices and experiences, and risk preferences, among other factors (Prokopy et al., 2019). Constraints on adoption are similarly heterogeneous, including not only economic and physical constraints to accessing certain technologies, but also formal and informal norms that guide what is and is not considered permitted (Hendrickson and James, 2005). Given how context-specific human decision making processes are, and how diverse farming contexts can be, very few "universal factors" explain agricultural practice adoption (Knowler and Bradshaw, 2007).

Nevertheless, some insights from the existing empirical research focused on ICLS can give some indications of the potentially important individual and external conditions influencing adoption or retirement of these systems. Research on crop-cattle farms in France has shown that farmers maintained ICLS when led by a personal motivation of seeking on-farm autonomy and risk avoidance, particularly in unfavorable pedoclimatic areas (Coquil et al., 2014; Ryschawy et al., 2013). In the US, cereal and dairy ICLS have been maintained among Amish farmers due to strong cultural norms that include community stewardship and limited introduction of new technologies (Brock et al., 2018; Parker, 2013). In Brazil, trajectories of adoption versus non-adoption of ICLS among beef cattle and soy farmers have been highly influenced by farmers own self-described entrepreneurial spirit versus preferences for existing traditions (Cortner et al., 2019; Gil et al., 2016). Labor limitations, especially for skilled labor, have been recognized in Brazil and Europe as a major barrier to adoption of ICLS (Cortner et al., 2019; Ryschawy et al., 2013). Lack of marketing options for diversified products and an unsupportive regulatory environment have also impeded adoption of crop-livestock integrated systems in Brazil, France, and the US across farming types (Garrett et al., 2017; Gil et al., 2016; Veysset et al., 2005), whereas a lack of regulatory impediments and climatic factors have supported greater adoption of ICLS, especially in cereal and beef cattle systems, as well and sheep and vineyards (Garrett et al., 2020; Niles et al., 2018).

In this paper, we analyzed local farmers' perceptions of a specific case of integrated crop-livestock systems, Integrated Sheep-Vineyard Systems (ISVS) in California, considering both vineyard managers and contractors (i.e. shepherds renting their sheep to vineyard managers). Our goal was to understand the factors that may enable or impede the widespread adoption of this niche system recognized to have positive impacts on vineyard economic outcomes and environmental benefits. To do so, we based our approach on exploratory semi-structured interviews with both adopters and non-adopters.

ISVS have been shown to be an economically and environmentally viable option for New Zealand vineyards (Niles et al., 2018), resulting in higher income by reducing costs associated with mowing (labor and fuel) and herbicide. In California, they also offer potential solutions to local challenges such as soil degradation and losses of soil organic carbon typical of semi-arid landscape (Brewer and Gaudin, 2020) and fire risk mitigation. We analyzed current management practices and perceptions of ISVS to highlight the major motivations and challenges for integrating sheep in vineyards and draw connections to the structural dimensions of sheep and vineyard systems in California that may underlay these perceptions.

As ISVS are still rare and progressive in California, they could be considered as a niche system. We thus applied the Multi-Level Perspective framework to understand levers favoring or impeding mainstreaming of this niche system (Geels, 2011). According to this framework, a dominant technological regime is locked-in (e.g. conventional commercial agriculture) by a broader structural landscape. Through levers called pull and push factors, a niche can emerge to disrupt the dominant system. This mainstreaming of technological niches is known as *"creative disruption"* (Kivimaa and Kern, 2016). Pull levers arise from changes in the landscape, whereas push factors arise through decentralized, grassroot processes. The Multi-Level perspective is considered seminal in transition studies, as it allows us to consider barriers and opportunities for a transition as a result of the interactions between different levels (i.e. scales). It has been used to consider a large diversity of socio-technical transitions toward sustainability from global challenges, including agroecological transitions and sustainable consumption transitions as reviewed by Gasselin et al. (2020). Here, we framed ISVS as a niche system, and then identified push and pull factors that would allow a greater adoption and development of ISVS.

2. Material and methods

2.1. Case study description

Vineyards are one of the largest land uses in Northern California. They are heavily associated with agri-tourism and wine production provides substantial economic benefits both to the state and the US, since California produces 85% of US wine (Franson, 2016). As a result, California's adoption of sustainable practices is of high importance, not only for environmental sustainability but also global wine production and markets. Here we examine niche efforts of livestock integration into vineyards, which may address a number of socio-economic and environmental concerns associated with grape growing in California. First, California is at the forefront of experiencing climate change, with increasing fire and drought risk (Brewer and Gaudin, 2020; California Department of Food and Agriculture, 2017). Expansion of vineyards in grassland and forested areas have raised fire risk as a major concern in recent years. Second, land and labor costs have rapidly increased, contributing to vineyard intensification and management by specialized third parties. Finally, conventional vineyard management practices rely heavily on inputs, fertilizer and irrigation water with simplified soil

management practices (Silverman et al., 2005). Organic vineyards avoid synthetic inputs but rely heavily on mechanization and labor (Steenwerth et al., 2015). All of these practices often result in soil degradation, losses of soil organic carbon combined with vulnerability of the vineyards to weather variation (California Air Resources Board, 2017). Still, 49% of vineyard use cover crops, which are the source of forage allowing for livestock integration which provides co-benefits for soil quality and pest management (Steenwerth et al., 2015).

Sheep grazing of forest understories and vineyard field margins, including neighboring grasslands, also provides unique opportunities to produce animal fiber and food while decreasing wildfire potential at reduced labor and environmental costs. Grazing reduces flame length and fire intensity, and can therefore shift grasses from a highly flammable and effective fire spreader into a natural fire barrier (Diamond et al., 2009; Ingram et al., 2013; Noy-Meir, 1995). Strategic implementation of grazing in and around vineyards on key private and public lands can meet multiple natural resource objectives, while also lowering fire hazard through reducing fine fuels, reducing fuel continuity. Finally, prescribed grazing for fire mitigation can have a variety of economic benefits compared to mowing by providing food and fiber and supporting the state's economy with production of goods and services. As such, prescribed grazing has gained recognition as a fire mitigation strategy in state policy in recent years.

For this study, we selected four major wine producing counties in California: Lake, Mendocino, Napa and Sonoma. These counties are located in the North Bay area which are globally recognized as a premium wine-growing country. In total, there are 3,618 wine grape growers across these counties, with 5% in Lake County, 11% in Mendocino, 38% in Napa and 46% in Sonoma. This covers a total wine grape acreage of 131,111 acres that corresponds to 9,513 acres in Lake county, 17,142 in Mendocino, 45,402 acres in Napa and 59,054 acres in Sonoma (USDA, 2017).

ISVS is a niche system and there is no quantitative data on the current status of ISVS adoption in the state, but the general perception among local experts and vineyard owners is that very few vineyards currently integrate sheep, according to the local farmer association CAFF (Community Alliance with Family Farmers). Yet, it is receiving increasing interest from vineyard managers, and ISVS are a growing part of the research and development portfolio of local agricultural organizations and Universities in the region, reflecting its perceived importance as a potential sustainability solution (UC Davis, California).

2.2. Study region and management characteristics

The study region is located in a semi-arid Köppen-type Csc climate (Beck et al., 2018) characterized by mild winters and an extended dry season from April to October. Sheep are typically integrated into vineyards using high-density, short-duration rotational grazing (~250 ewes/acres for ~1–2 days) when vines are dormant and when most of the winter precipitation occurs. The understory can be grazed once for termination before bud break or multiple times during vine dormancy. Sheep are frequently rotating through small 1-acre paddocks and then removed from the system to graze on fallows or on nearby pastures and cover cropped fields. Grazing fallows can help mitigate fire risk and grazing on cropland has been shown to impact multiple ecosystem services and functions such as soil organic carbon accumulation (Acosta-Martínez et al., 2010, 2004; Brewer and Gaudin, 2020; de Faccio Carvalho et al., 2010; Franzluebbers et al., 2014; Fultz et al., 2013), nutrient provision (Acosta-Martínez et al., 2010; de Faccio Carvalho et al., 2010; Franzluebbers et al., 2014) and the underlying soil microbial communities (Acosta-Martínez et al., 2004, 2010; Beck et al., 2018; California Irrigation Management Information System, 2021; de Faccio Carvalho et al., 2010; Fultz et al., 2013).

2.3. Data collection and analysis

During August 2018, we conducted interviews with seven farmers practicing ISVS, including five vineyard managers and two contractors, and seven non-integrated vineyard managers. We considered the farmers integrating sheep grazing into vineyard as adopters, as the practice was new in the area. Contractors were already shepherds before but their sheep were grazing only fallows, grasslands and cover crops and vineyard managers were not integrating sheep before. Here we call ISVS all farming systems involving this new practice of reintegrating crops (wine grapes) and livestock (sheep). All interviewees that were not integrating sheep in their vineyard are called non-adopters.

To consider farmer perceptions of sheep integration in vineyards, we did not aim for statistical representativeness, but instead aimed to sample across actors with a wide range of integration conditions to obtain a diversity of perspectives. These conditions included the size of the vineyards, the status of the vineyard manager as owner or employee, the number of sheep involved, and the organization of grazing (sheep owned and/or leased) (Table 1). We then paired each ISVS interview with a nearby non-integrated farm. Such a "case-control" approach is common and appropriate in exploratory inductive research (Eisenhardt, 1989). We continued the interviews as long as new points of view emerged, that is, when no new advantage, lever nor barrier was cited by the interviewees and no new lever was suggested (Beudou et al., 2017). Sampling until "saturation" of viewpoints is achieved is also a standard approach in inductive qualitative research (Corbin and Strauss, 2014).

We identified the interviewees through our local partner, the Community Alliance with Family Farmers (CAFF). Forty-eight vineyard managers were contacted by email. Eighteen of them responded positively and were called over the phone to schedule an interview. While only fourteen interviewees, our sample represents 5.9% of the vineyard acreage of the four counties (7,724.5 acres on 131,111 acres in total), similar to previous studies with the same research design (Niles et al., 2018).

The interview guide was developed based on an existing ISVS survey used in New Zealand (Niles et al., 2018) and in consultation with CAFF to include new relevant context-related questions around fire management, vineyard irrigation, etc. for California. The first part of the questionnaire focused on farm attributes (e.g. farm size, tenure situation, products grown, operator's background and education, etc.). The main part of the questionnaire was open-ended, asking vineyard managers and contractors what they perceived as advantages or barriers of ISVS and which type of levers could favor its adoption. All interviews were recorded and lasted on average an hour, the maximum being three hours when sheep were integrated in the system, as practices were detailed. We obtained IRB ethics approval before conducting the interviews (Protocol #: 3918X, Boston University).

We used inductive content analysis method and open coded our interviews into key themes emerging from the interviews (Elo and Kyngäs, 2008). Following methods elaborated in (Beudou et al., 2017), we re-listened to all the interviews to select relevant sentence fragments. We organized these fragments into pre-defined sub-categories based on the general framework of adoption (Advantages, Barriers and Levers) (Prokopy et al., 2008). We grouped sub-categories into these main categories through an iterative coding approach, re-listening to the interviews and grouping emerging themes according to our pre-existing mental models of how structural and individual contexts influence farmer perceptions (Cortner et al., 2019; Niles et al., 2018). We carefully limited redundancies while prioritizing one category only for each fragment, when it may be classified into two different categories. For instance, a vineyard manager mentioned that the fact that "people like sheep" was used as a marketing advantage when putting a sheep picture on the bottle of wine so we decided to classify this fragment into socio-economic category rather than socio-cultural category, as it was presented as a marketing option. Interviewees' quotes were used to illustrate the analyses.

Table 1
Description of the farms sampled.

Interviewee	Location	Area of vineyard *(acres)*	Cover crops seeded	Status of sheep	Number of ewes
Adopters					
A1 *(vineyard owner)*	Sonoma	4	Yes, on all area: grass-legume mixture	owned	11
A2 *(vineyard owner)*	Mendocino	100	Yes, on all area ryegrass+clover	owned	200
A3 *(vineyard manager)*	Napa	160	Yes, on all area: brassicacea+ triticale+ legume	owned + hiring contractor	18 400
A4 *(vineyard manager)*	Mendocino	960	Yes, on all area Clover +triticale/oat/ barley/ryegrass +mustard/radish	hiring contractor	2000[a]
A5 *(vineyard manager)*	Lake	2 000	Yes, clover-grass mixture	hiring contractor	3700[a]
A6 *(shepherd)*	Napa	n.a.	n.a.	contractor themselves	2 000[a]
A7 *(shepherd)*	Lake	n.a.	n.a.	contractor themselves	3 700[a]
Non-adopters					
NA1 *(vineyard owner)*	Sonoma	3	No	n.a.	
NA2 *(vineyard owner)*	Lake	3.5	Yes, on all area: Clover mix	n.a.	
NA3 *(vineyard owner)*	Sonoma	20	No, dry farming	n.a.	
NA4 *(vineyard manager)*	Sonoma	55	No, dry farming	n.a.	
NA5 *(vineyard owner)*	Napa	56	No	n.a.	
NA6 *(vineyard owner)*	Napa	105	Yes, on all area: Barley-oat	n.a.	
NA7 *(vineyard manager)*	Napa	670	No	n.a.	

[a] Numbers of sheep are similar because contractors A6 and A7 are respectively renting their sheep to vineyard managers A4 and A5.

We then contextualized these interviews using the Multi-Level Perspective framework to analyze the levers favoring or impeding mainstreaming of this niche system and the different patterns in socio-technical transitions (Geels, 2011). It considers in particular that: (i) a dominant system is in place (e.g. conventional commercial agriculture), (ii) determined by a broader landscape, acting on the dominant system through pull factors, and (iii) that niche technologies can emerge to disrupt this dominant system through push factors. Thus, push factors are emerging from the niche context and function as bottom-up processes whereas pull factors are macro-economic, institutional, or climatic factors coming from the landscape. We applied the Multi-Level Perspective to ISVS to organize the levers mentioned by the interviewees in terms of push and pull factors that could disrupt the current agricultural regime (specialized systems) to favor the development of this niche system (ISVS).

3. Results and discussion

3.1. Farm characteristics and farmers' general perception of ISVS

Our sample covered a large diversity of farm characteristics (Table 1). The size of the vineyards ranged between 3 and 1000 acres (median = 78 acres) and 7 vineyard managers within the 12 interviewed were vineyard owners as well. Within the 12 vineyard managers interviewed, the half only sold their grapes, while the other half also produced wine. Six vineyard managers believed they were implementing organic or biodynamic practices, but only three were being certified for marketing advantages. The remaining three ones were convinced of the good practices implemented but did not want to enter in the certification process as they estimated a bad cost-benefit ratio, i.e. too much paperwork for low marketing advantages. The two contractors were based in California and rented their sheep to vineyard managers to graze cover crops. We observed three different ways for vineyard managers to integrate sheep in vineyards in the area, which were corroborated by CAFF observations and expertize of the area. The first type had their own sheep and were able to let them graze in their farm all year long. They owned the sheep they used because they *"love sheep"* and wanted to gain more training in this area. This occurred mostly on smaller vineyards (<100 acres), where vineyard managers where vineyard owners as well. The second type were intermediate vineyards (100–200 acres) who owned some sheep, but also leased sheep to contractors. This group leased herds ranging from 200 to 500 heads during vine dormancy (three months in winter), when a lot of grass was available in the vineyard. Their own sheep (around 20–40 heads) grazed the rest of the property during the remainder of the year. The third set relied on contractors and were the biggest vineyard with more than 700 acres. In the two last types of organization, vineyard managers were employed by the vineyard owner.

The contractors interviewed had large herds ranging from 1,000 to 4,000 sheep and hired shepherds to help them during the high season of dormancy in the winter. They were thus able to put sheep on different vineyards at the same time of the year. The seasonal organization was the key to their system. When sheep were not grazing in vineyard, contractors rented some grassland, such as alfalfa in Southern California or were paid by crop farmers for cover crop grazing during spring and summer. During the summer, some of them were paid by the Bureau of Land Management to graze fallows to limit fire risk.

Within the seven vineyard managers that did not integrate sheep, three had previously integrated sheep on their vineyards but no longer integrated them. Two of them shifted away from ISVS because their contractor quitted his job. The latter vineyard manager stopped using sheep because the vineyard owner changed and was not interested in the practice, but this vineyard manager would like to have sheep again in the future and is trying to convince the vineyard owner of the benefits highlighting input and work cost savings and marketing advantages. In the area, two main types of relationships were observed between vineyard managers and vineyard owner (i) moreoften, vineyard owners own the vineyard for leasure and let the vineyard manager take all decisions

or (ii) as it is the case here, the vineyard owner is a wine producer, e.g. knowledgeable of management practices, and takes the decisions.

The interviewees confirmed that having sheep grazing into vineyard was not a common practice in the area. Vineyard managers integrating sheep, the two contractors and one vineyard manager that used to have sheep (i.e. who stopped using sheep because of owner change) were convinced of the benefits of ISVS as they were trying to decrease the environmental footprint of their operation (5 of them were certified organic). Vineyard managers integrating sheep did not try to quantify the benefits, but tended to minimize the barriers. As one of them said, *"I do not need any quantification, I am sure it is beneficial"*. Of the remaining six vineyard managers not integrating sheep, two were interested in having sheep, one was convinced of the benefits, but did not want to manage sheep and three had a negative perception of ISVS, including animal welfare concerns due to aversion training with lithium chloride and a belief that integrating sheep was not adapted to their specific vineyard. The two vineyard managers, who believed ISVS was not appropriate for their farm were dry-vineyard managers that had less than 20 acres. They were concerned about high competition for water between the crop and cover crops for sheep. These two dry vineyard managers used arguments such as, *"I have seen the degradation done by sheep and they are selecting the weeds and killing the blooming ones,"* or explained that sheep fertilization was of no interest to them in comparison to grape pumice, even if they were in fact buying some manure at neighboring farms. These assertions were opposite to the findings of research on these topics (Brewer and Gaudin, 2020; Niles et al., 2018).

3.2. Current practices to manage sheep in vineyard are satisfying but understudied

All vineyard managers using sheep were having them graze cover crops during dormancy in the winter (from post-harvest until pre-budbreak), as was observed in New Zealand (Niles et al., 2018). To graze cover crops, sheep were moved between parcels every 2–3 days, with a high density of 10–15 sheep/acre – the less intensive one using 3 sheep/acre for a longer time while the contractors would use up to 30 sheep/acre for no more than 2–3 days to limit soil compaction. Each acre could thus be mowed about 2–4 times, according to the type of grass mixture (natural or sawn). The five vineyard managers integrating sheep designed specific cover crop mixes combining legumes, cereals and sometimes brassicas for adequate feed. One vineyard manager integrating sheep designed the cover crop mixture together with the sheep contractor through, *"a bit of conversation to adjust our needs"* would help fatten sheep while having a soil cover for an *"all win scenario."* As explained by a contractor, *"Vineyards and orchards are priced to be competitive with tractors."* Contractors evaluated their costs of mowing to be 50–80% of the mechanical costs. The prices paid by the vineyard managers to contract them ranged between $60-$200 per acre. The price was calculated on the savings made by the vineyard manager and could vary according to several parameters, including: (i) the quality of the grass, i.e. the price paid to the contractor could be lower if a legume mix is purposely sown by the vineyard manager and thus allows high feed quality; (ii) the number of acres available, i.e. the price would decrease if more land is available given the upfront logistic costs of transporting the sheep to the vineyard relative to the benefits of grazing but the price would increase if there are larger distance to move the sheep, more fences to install and/or dangerous landscape-hill to graze; and (iii) the type of activities made by the sheep, ranging from a simple mowing of grass in the vineyard to leaf-plucking, which is expensive and requires a more specific skilled workforce for the vineyard manager and more observation for the contractor. Among these factors, the first two (nutritional composition and grazing area) were indicated to be critical. Contractors stated they would only accept the arrangement if the cover crops allow their lambs to fatten and cover their logistic cost - *"this is a lot of logistics"*. Social capital, specifically trust, was indicated as another important element of integration by one contractor, what is in line with the importance of the "gentleman handshake" (Fisher, 2013). He stated he would *"rather shake hands"* than write a formal contract. The ability to avoid formal contracts through trust has been found to be important in other integration studies between neighboring crop farmers and livestock farmers developing buy-sell scenarios of fodder and grain in South-western France (Ryschawy et al., 2017).

Sheep were used in four vineyards for leaf-plucking during the growing season and one other would like to try it. The contractors were responsible for fencing and training their sheep, whereas most other did not want to try it, explaining that *"I doubt that the sheep are technical, precise, on the leaves they are picking."* The cost of sheep rental to contractors for leaf-plucking were slightly higher around $65-$75 per acre for one grazing event. The remaining three vineyard managers were afraid of having sheep in the vineyard just before and right after budbreak. All vineyard managers having sheep and contractors were against "aversion training" (e.g. using a measured dose of a poisonous lithium chloride (LiCl) on the leaves to train sheep to not eat them) for animal welfare reasons. Contractors explained they limited damages on the grapes being careful to move sheep out of the vineyard before budbreak to limit risk, commenting that *"you should put them out really quickly before the bud reaches the size of a popcorn."* Two vineyard managers kept sheep year-round using Babydoll sheep as they were smaller. Only two vineyard managers used this type of sheep because they were more expensive than regular breeds (about $500 for a baby doll baby ewe instead of $200-$300 for regular breed) and worth less on the meat market. One vineyard manager preferred mowing the weeds during budbreak and giving the green chop to the sheep as feed without risking any loss in the grape.

3.3. A rather positive perception of ISVS

Fig. 1 is presenting the main categories of perceived advantages and barriers cited by the 14 interviewees. The main advantages perceived are socio-economic and eco-environmental while the main barriers were related to farm practices, and in particular sheep management, and socio-cultural barriers. Interviewees cited 17 advantages that were mostly shared between adopters (including vineyard managers and contractors) and non-adopters. Still, interviewees mentioned 37 barriers to ISVS implementation. 12/37 barriers were only mentioned once and could be considered as a one-off perception not widely held. The main advantages and barriers are mentioned in Table 2 and 3 respectively.

3.3.1. Perceived advantages of ISVS are mainly related to socio-economic and eco-environmental dimensions

A main advantage of ISVS perceived by vineyard managers was reduced labor for mowing through the integration of sheep. All but one interviewee said that sheep provided significant labor savings (2–4 mowing passes) and cost savings of about $87 to $174 per acre. According to one vineyard manager, costs of contract grazing was similar to mechanical costs, *"on a 160-acre ranch, sheep would cost about $80–120 per acre per year to mow,"* but mentioned that a lot of other co-benefits were not valued. Vineyard managers using sheep for leaf-plucking would save up to $643 per acre according to sheep contractors, even though risks and quality of work have not been quantified with regards to skilled labor. One vineyard manager had estimated that tractor use decreased by 20% using the sheep for mowing and leaf-plucking. All vineyard managers underlined fuel savings as a result of integrating sheep. Still, contrary to Niles et al. (2018), only two vineyard managers highlighted a potential decrease in herbicide use. This is because most of them were already trying to use mechanical weeding instead of herbicides.

All interviewees acknowledged the potential advantages of sheep on the environment through improvements in soil quality (fertility, nitrogen, carbon, soil health and microbial activity were mentioned). As one vineyard manager said: *"I don't need to be a microbiologist to see the soil health improvements."* Still, vineyard managers integrating sheep did not

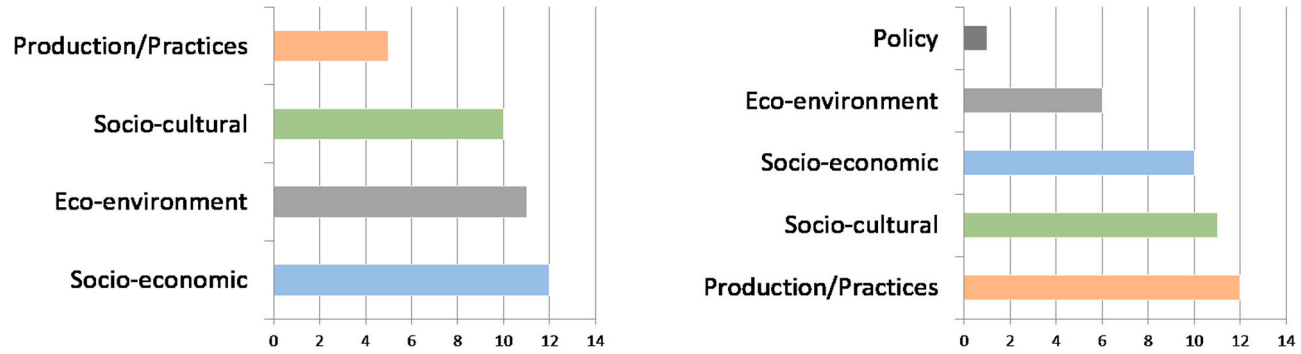

Fig. 1. Main categories of advantages (left) and barriers (right) cited by the interviewees regarding ISVS. *(The horizontal axis corresponds to the number of interviewees citing at least one item in the category of advantage or barrier considered, n=14)*

Table 2
Main advantages toward the adoption of ISVS according to the interviewees.

Category considered	Advantage cited	Number of farmers citing		
		Total	*Adopters Integrating sheep*	*Non-adopters Not integrating*
Socio-economic	Limiting labor cost in the vineyard *(e.g. mowing/weed control/leaf-plucking)*	12	*7*	*5*
	Marketing purpose *(e.g. put sheep on the bottles of wine)*	7	*5*	*2*
	Fire safety through grazing *(wineries, terraces)*	5	*3*	*2*
Socio-cultural	Attachment of farmers to sheep	8	*6*	*2*
	Cultural value given to sheep historically in the area	4	*3*	*1*
Eco-environment	Improving nutrient cycling *(fertilization, available Nitrogen)*	9	*7*	*2*
	Limiting fuel and machines used for mowing	7	*5*	*2*
Production/Practices	Meat produced	4	*4*	*0*
	Wool produced	2	*2*	*0*

Table 3
Main barriers toward the adoption of ISVS according to the interviewees.

Category considered	Barrier cited	Number of farmers citing		
		Total	*Adopters Integrating sheep*	*Non-adopters Not integrating*
Socio-economic	Sheep not well paid for meat and wool (e.g. cost to take the wool away)	4	*4*	*0*
	Fencing represents a lot of cost and work	5	*3*	*2*
Socio-cultural	Local farmers do not like aversion training with "poison"	5	*3*	*2*
	Farmers are slow and scared to change	3	*3*	*0*
Eco-environment	Sheep are not skilled on leaf plucking	3	*2*	*1*
	Grape pumice compost and green manure work better as fertilizer	3	*0*	*3*
Production/Practices *(e.g. sheep management)*	Destruction/breaking of irrigation lines	8	*6*	*2*
	Increased workload to manage sheep (i.e. *"take care of them all week long 24/7")*	7	*5*	*2*
	Risk to let the sheep eat the buds	7	*5*	*2*
	Risk of predators eating the sheep	7	*4*	*3*
Policy	Fresh food act could limit having sheep in vineyard	1	*1*	*0*

limit their fertilizer use. Only one vineyard manager was not convinced about the benefits of sheep on soils. Even if vineyard managers assumed there were lower chemical nitrogen needs as a result of sheep grazing, they did not quantify or calculate the difference resulting from including manure and thus were not confident enough to limit their fertilizer use. This corroborates previous studies on the limitations of collaborative arrangements between crops and livestock farms to limit chemical nitrogen use. Studies of cattle-crop farmers in France found that they maintained or increase their level of chemical nitrogen use and/or number of animals after integration, rather than decreasing it as it was expected by researchers and advisors (Asai et al., 2014; Regan et al., 2017).

Using sheep as a tool for fire risk mitigation was mentioned as an important advantage in this area of California. As vineyard managers had recently experienced massive losses of vineyards and infrastructure from widespread fire, sheep grazing was used by all to reduce aboveground biomass and associated fire risk. This advantage is in line with previous studies highlighting the positive role of grazing animals in reducing fire risk, and in particular sheep and goats grazing fallows in comparison to mechanical mowing (Colantoni et al., 2020; Lovreglio et al., 2014).

Marketing aspects (e.g. commercializing new bottles of wine with sheep on the sticker or organizing wine tasting promoting sheep and tasting lamb) were cited as benefits of adoption, but mostly by vineyard managers employed in bigger wineries. Marketing advantages were seen by all adopters as a strong argument to convince vineyard managers to integrate sheep, even if they have not been directly quantified unlike input savings. Finally, socio-cultural dimensions were very strong drivers for integrating sheep in vineyards. Attachment to sheep was cited by eight interviewees. One vineyard manager argued for having sheep based on sentimental reasons: *"Just because, I like sheep, I like them."* Even three vineyard managers not integrating sheep stated that sheep were cute. This affection was tied to nostalgia and family tradition; four vineyard managers mentioned that their grandparents had

sheep or that they used to see sheep in the area when they were younger. Prior familiarity and nostalgia for having animals and/or having growing up on a farm with animals and/or access to reliable sheep contractors appear to be important factors to overcome challenges associated with animal management (Garrett et al., 2020; Niles et al., 2018), whereas existing habits, especially with no animals on most local farms, and fear of change can exacerbate concerns (Prokopy et al., 2008).

3.3.2. Perceived barriers to ISVS are mainly related to sheep management

The major category of barriers mentioned by the interviewees was related to the farming practices and especially management of the sheep and risks associated with implementing ISVS. As a vineyard manager owning sheep explained, *"sheep have no office hours 9–5, 5 days a week!"* All vineyard managers integrating sheep and contractors had mentioned the time needed for fencing, watching the animals to decrease predator risk and training dogs. Quality of the work done was another issue. As mentioned by one vineyard manager, "*Sheep are not skilled and they won't do the quality of work I am doing."* Eight vineyard managers mentioned risk of damages to irrigation lines. This was perceived as a bearable risk as fixing irrigation drips is common. The risk of having the sheep eating some grape buds was mentioned by seven vineyard managers (five having sheep and two not). They said that *"sheep love grape fruits!"* and that they could even *"stand on their back legs to get some."* The risk of sheep compacting soil was mentioned by four vineyard managers, still explaining that this could be prevented with appropriate management, e.g. limiting overgrazing especially on wet soils. A contractor mentioned that *"a tractor wheel would have a lot more instantaneous compaction effect than a sheep on the soil."* Veterinary costs and difficulties to find a qualified veterinary were mentioned since sheep are not common in the area. Another important barrier was the lack of marketing options for meat and infrastructure for processing fiber to add value to sheep products. This was underlined by Cortner et al. (2019) and (Ryschawy et al., 2014) as a major barrier for other cases of ICLS. This is in line with the fact that at a landscape level, there were very few sheep in California what has only been mentioned by contractors and contributed to explain the lack of supply chains in comparison to livestock regions, such as New Zealand (Niles et al., 2018).

Lack of information and technical experience on how to manage sheep in vineyards were noted by several vineyard managers. As one non-adopter explained *"I was doing some random searches [on cost-benefit analysis] because nothing is available."* Within vineyard managers, both adopters and non-adopters highlighted that *"Farmers are slow to change"* or *"scared to change."* This was not surprising as *"farmers need to look over the fence to observe neighbors being successful and observe before changing the practices,"* according to one adopter but ISVS were not well developed in the area. One non-adopter explained that he recognized the benefits of ISVS, but mentioned that it "*scares me out.*" These perceived barriers suggested a lack of social capital, in particular of "bonding" ties between vineyard managers and contractors in general, except for those already having relationships. Sharing knowledge between vineyard managers having already a successful experience with sheep in their vineyard and their unexperienced peers was mentioned as a key lever to encourage collective organization and trust establishment (Cofré-Bravo et al., 2019).

Vineyard managers were often lacking relationships to advisers trained in livestock management, especially in areas where livestock is not common, such as vineyards or fallows. The separation in the crop and livestock knowledge has already been cited as a main barrier to ICLS (Garrett et al., 2020; Martin et al., 2016). The competency of such advisers would be key in "bridging" ties and improve social capital toward the development of ISVS. The loss of the tradition of sheep herding was also mentioned, *"this is not in the culture."* This barrier has been underlined as a strong limiting factor to livestock reintroduction in areas where livestock has disappeared, along with the loss of technical management skills (Ryschawy et al., 2013).

As in other regions (Ryschawy et al., 2017), the logistical complexity for beyond farm organization was cited as a major barrier of ISVS, particularly for hiring independent sheep operations to graze vineyards. As a vineyard manager integrating sheep explained: *"the shepherd has his own logistics and transportation costs, so if the weather is not good, he won't come and when he leaves, we sometimes have to mow because weeds germinate again after the sheep left."* These issues reflect broader weakness in the social capital system for integration – specifically a lack of established, trustworthy contract systems. These systems are needed to reduce the managerial intensity and financial costs and risks associated with coordinating livestock in cropping systems, as suggested Asai et al. (2018).

3.4. Push factors as main levers suggested to favor ISVS development

The detailed list of 28 levers suggested by interviewees was organized into eight categories. Pull factors and the need for policy change and research were not often cited by the interviewees. Still, given that vineyard managers asked for reliable quantitative information which does not currently exist according to them despite strong effort in UC Davis (including system experiment and vineyard managers training), additional research would be needed to get reliable information on best management practices and inform case-studies. Subsidies for up-front costs for introducing sheep or avoid risk (insurance for sheep) were mentioned as relevant for smaller vineyard managers and contractors. Certifications or labeling options were not often mentioned, despite local efforts by non-profit organizations to develop value-chains and incentives for carbon sequestration and to create a new market for climate-beneficial wool (Fibershed network). Such pull factors maybe highly important to convince vineyard owners of the benefits of ISVS and encourage them to decide to adopt the practice of sheep grazing into vineyards. Vineyard owners have the power of decisions of adopting sheep grazing or not in the vineyard and should thus be targeted through training and public policies, as well as the vineyard managers.

On the contrary, push factors were largely mentioned as levers by the interviewees. Vineyard managers focused in particular on using contractors as a way to cope with herd management barriers, redesigning the vineyards to better cope with the challenges of ISVS, and informational needs regarding the need to improve training on technical aspects, such as sheep management into vineyard and cost-benefit analysis.

3.4.1. Contractors as a way to cope with herd management barriers

Contractors were seen as major actors to deal with most of the sheep management barriers cited. Contractors had extensive knowledge of animal management and costs are less or equal to regular labor and tractor costs per acre. As one contractor said about vineyard managers in the area: *"they all talk to each other, and so we do a good job, we don't muddy up their field, we move them on time, we do a good job."* He explained that vineyard managers would watch what their neighbors were doing and might comment, *"I thought they were doing compaction, but that looks pretty good, they are saving money over there."* Furthermore, contractors were seen as relevant people to show that ISVS had benefits and wished to build a social network around ISVS Best Management Practices.

Yet, as mentioned above, these contractors were not yet well integrated into vineyard knowledge and social systems. Civil society organizations or local governments could help foster exchange of knowledge by building stronger farmer networks and associations that include sheep contractors and vineyard managers. For example, vineyard managers wishing to develop ISVS could access the network to find a contractor who could train them on how to integrate sheep management in their system. As one vineyard manager not integrating sheep said, *"I would like to start a little at a time and maybe hire a contractor for some years and observe and then see if I should buy my own sheep."* The growth of these umbrella organizations could also strengthen the service market and help provide the two types of ties that are necessary to foster

innovation: "bonding" ties with other shepherds and livestock keepers and "bridging" ties with vineyard managers, advisers and researchers (Cofré-Bravo et al., 2019).

3.4.2. Redesign vineyards and train farmers to manage sheep properly in vineyards

To limit potential damage from sheep, one suggestion was to redesign the vineyards or at least give new vineyard managers some guidelines on how to design their vineyard for ISVS, as changes are difficult to implement after the vineyard is planted. For instance, they would recommend having higher vines to limit the risk of buds or grapes being eaten and having higher irrigation system to limit potential damage (3.5–4 feet high). Other vineyard managers integrating sheep would recommend using baby doll breeds to limit damages, but this was not considered as beneficial as baby doll sheep are three times more expensive than regular breeds and are less profitable. Finally, some recommendations around irrigation systems and the type of plant mixtures to use for dual-purpose soil cover would be necessary for such a design. This approach should rely on existing successful case-studies of vineyard managers integrating sheep and also capitalize on systems-level experiments that have already been done by local researchers.

3.4.3. Fill in the information gap around ISVS

Developing training and information available about ISVS was seen by vineyard managers as a powerful lever. Interviewees, especially those not integrating sheep, were seeking quantitative information about ISVS in their area. Vineyard managers in the study region wanted access to successful case-studies detailing cost-benefit analyses, up-front costs, labor specific to the animals for different cases, and best management practices (type of cover crop mixtures to be used, grazing intensity and time of grazing, type of fences, etc.). Vineyard managers also suggested that field days on demonstration farms (real farms or research farms) would have a strong potential to encourage vineyard managers toward ISVS and to train them on ISVS as new skills are required. Vineyard managers underlined the importance of getting reliable and independent public information rather than information from companies selling products. The recent studies and ongoing system experiments at UC Davis were contributing to inform data on the effect of sheep grazing on soil quality (Brewer and Gaudin, 2020). Still, one vineyard manager explained *"You never know who to trust!"*. This last remark re-emphasize that existing "linking ties" between vineyard managers' networks and broader research institutions that study sheep grazing or ISVS are not sufficiently strong (King et al., 2019). Moreover, given skepticism over certain sources of information (e.g., private vendors), knowledge sharing efforts must consider existing information networks, including the need for farmer-to-farmer networks (Lubell et al., 2014).

4. Conclusion and outlook

Our inductive analysis is a promising first insight into farmers' perceptions and motivations toward ISVS adoption in California. We found a large potential for greater adoption as there was a positive perception of ISVS among both adopters and non-adopter interviewees regarding

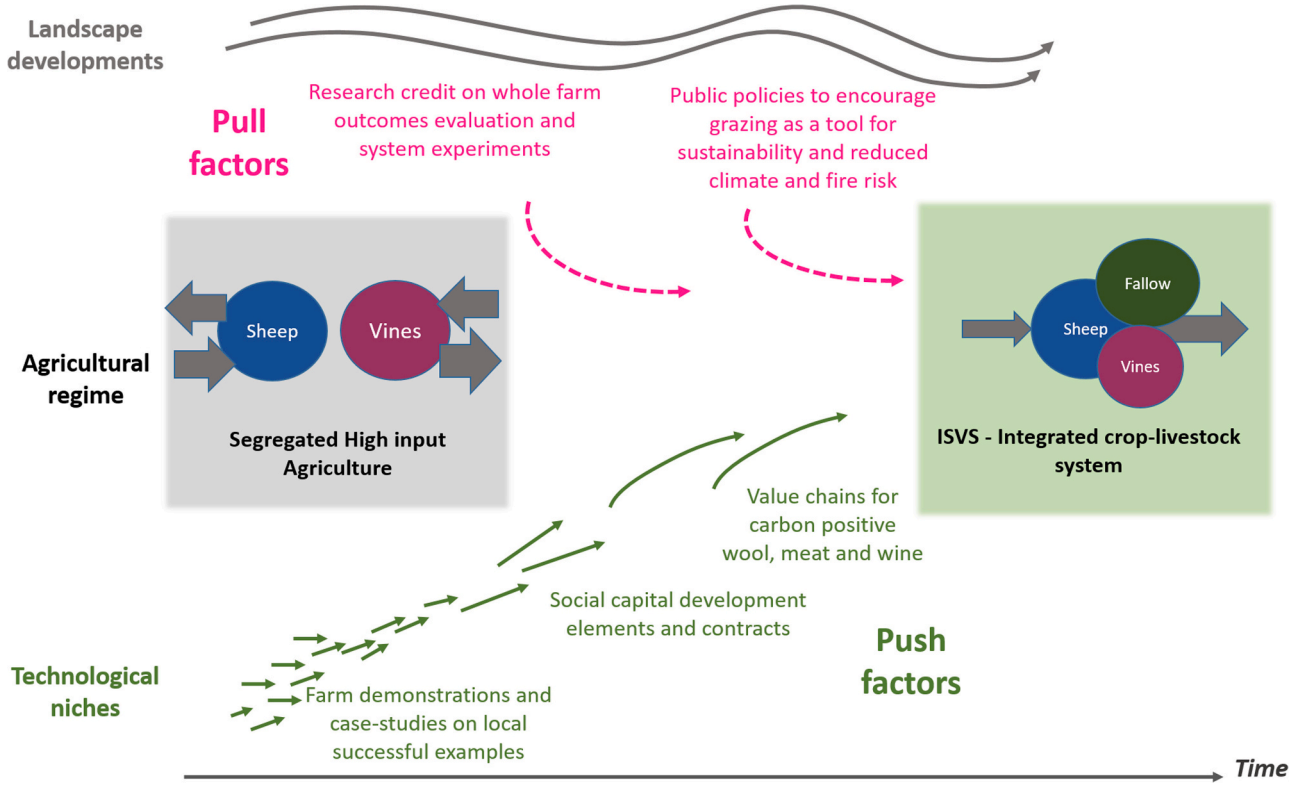

Fig. 2. Multi-level perspective and analysis of push and pull factors that could disrupt the existing agricultural regime and favor mainstreaming of ISVS (integrated sheep-vineyard system) agroecological niche (adapted from Garrett et al., 2020). The figure is representing (i) the dominant system in place as segregated vineyard and sheep production (e.g. conventional commercial agriculture), called Segregated High input Agriculture. This corresponds to the current specialized production systems with high level of inputs for vineyard and animal feeding with no or few interconnection locally between animals and crops and is integrated in global competitiveness (ii) broader landscape agents acting on the dominant system through pull factors, e.g. macro-economic and institutional factors and (iii) the ISVS niche that can emerge to disrupt this dominant system through push factors, functioning as bottom-up processes. The ISVS, as a type of integrated crop-livestock system, has locally interconnected sheep and vineyard through grazing, what is limiting external inputs, fire safety and allows having local carbon-positive market value chains. The size of the arrows reflects their relative individual strength. Individual pull factors have a strong influence while push factors often have a small individual influence which can gain importance if they are numerous and taken collectively.

agronomic, environmental and economic outcomes. All vineyard managers integrating sheep were satisfied with ISVS because they experienced labor and fuel savings, soil quality improvement and marketing advantages. However, the barriers cited to implement ISVS on their vineyards remain numerous, in particular relating to sheep management and current technical segregation between crop and livestock sectors. Despite a current move toward ecological intensification of high value perennial systems and the large availability of ungrazed perennial areas, the adoption of ISVS remains low. Our analysis, summarized in Fig. 2, is in line with the review of Garrett et al. (2020), highlighting the role of social and ecological landscape in locking-in agricultural regimes while inhibiting the emergence of agroecological niches, e.g. ICLS in commercial farms.

Numerous push factors were cited by the interviewees, such as building social capital through networking between vineyard managers and contractors, improving marketing pathways to value carbon-positive wool and meat and wine products and redesign vineyards to adapt them to sheep management. Improving marketing aspects may encourage vineyard owner to accept introducing sheep in the vineyard as a marketing advantage if saving cost and labor is not a sufficient argument. As a vineyard manager mentioned, he had to stop using sheep because the vineyard owner decided it so vineyard owners should not be forgotten to encourage ISVS mainstreaming. A higher international selling price for wine produced in ISVS could be considered as key pull factor to motivate vineyard owners. Though such pull factors were not often mentioned, they remain key to mainstream ISVS niche. The broader landscape favoring specialization has led to deeply entrenched cultures, experiences, institutions, and networks that give rise to the numerous implementation barriers, cited by the interviewees. Among levers to mainstream ISVS, policy and research were only cited once. Still, our results highlight major research avenues to mainstream ISVS systems, considering both the biotechnical and socio-economic dimensions.

On the biotechnical aspect, system experiments to redesign vineyards and better manage sheep are needed to tackle the informational needs of vineyard managers and cost-benefit analysis. System experiments should be continued where they take place and scaled-out to evaluate the effect of grazing with regards to mowing on different economic and environmental dimensions, including: (i) soil quality, and in particular the effect on fertilizer use on mineral fertilization, (ii) effects on grape and meat quality, (iii) logistics and grazing organization regarding different vineyard designs and sheep breeds, and (iv) fire risk mitigation management. Such experiments, combined with on-farm data collection, would allow a greater understanding of shifts in soil health, productivity and input use efficiency (water, fertilizer, energy, and labor) with grazing under different practices. Cooperative Extension in California, Resource Conservation Districts and agricultural non-profits are well suited to help deliver information on many aspects of these challenges, including technical assistance and market. To date, no study has been conducted on the payback periods for integrating sheep into vineyards in different contexts and farming system strategies.

Qualitative studies should be considered as relevant as well. Too little research has been developed on understanding farmers' motivations as we did here, whereas considering farmers' intrinsic motivations is key to encourage change (Rodriguez et al., 2009). Co-designing scenarios to implement territorial ICLS, e.g. ISVS, would be relevant economically for both vineyard managers and shepherdswhile allowing reductions in pesticide use and fire risk. We thus encourage exploration of relevant spatial scenarios through co-design of collaborative arrangements between different types of farmers on a broader region, as developed in previous studies on collaborative arrangements for crop-livestock integration (Asai et al., 2014; Moraine et al., 2017; Regan et al., 2017; Ryschawy et al., 2017).

Finally, there is a need for long-term research to evaluate the social, environmental and economic services provided of ISVS, and ICLS broadly, and design targeted policies to encourage their development. Developing research to evaluate the economic, environmental and social services provided by ISVS over multiple years could favor the development of specific payments for these services (Dumont et al., 2019). Whole farm outcomes should also be addressed over longer time horizons to ensure farmers' risk mitigation to climate change and markets. Practice changes could thus be encouraged by appropriately targeted policies, encouraging good practices, including carbon credits and fire risk mitigation as recommended by (Prokopy et al., 2008). Research would be needed to better know how to adapt policy support adapted to farmers' needs. Further research should be made as well to study the development of marketing options, such as labeling the services provided by ISVS, including carbon-positive wool initiatives that could be interesting levers. As the local demand for sheep meat is low except for lamb, specific branding options and market research should be developed. Finally, research is needed to better understand the role livestock can play to valorize areas or recycle byproducts via ISVS (van Zanten et al., 2016). Adjustment of current regulations are key to allow for a circular economy, adjusting current prohibitions on integration and material reuse, as suggested by Garrett et al. (2020) concerning ICLS in general.

All these considerations resonate with broader analyses tracing the strong structural factors that continue shaping research on specialized technology or practice rather than supporting system transformation (Vanloqueren and Baret, 2009). Locked-in research agendas on specialized systems and a narrow set of economic or environmental outcomes affects education programs as well, leading to specialized advisers, farmers and other agricultural actors, and contribute to shaping policies encouraging specialization. If ISVS is found to be socially beneficial through increasing research, current bottom-up "creative disruption" efforts by farmers and local organizations to support ISVS will need to be supported by changes in pull factors, including new educational programs and policies.

CRediT authorship contribution statement

Julie Ryschawy: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Funding acquisition. **Sara Tiffany:** Methodology, Investigation, Writing – review & editing. **Amélie Gaudin:** Methodology, Writing – review & editing, Funding acquisition. **Meredith Niles:** Methodology, Writing – review & editing. **Rachael D. Garrett:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition.

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