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Official URL: http://dx.doi.org/10.1017/9781009093569.006
DOI: http://dx.doi.org/10.1017/9781009093569.006
EPrint URI: https://eprints.glos.ac.uk/id/eprint/11057

5 *Constrained Sustainability and Resilience of Agricultural Practices from Multiple Lock-In Factors and Possible Pathways to Tackle Them*

An Assessment of Three European Farming Systems

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5.1 Introduction

Following the Second World War, agricultural production for food security was prioritised, and the use of chemicals in agriculture started to override previous agricultural practices dominated by crop rotation, diversification and traditional knowledge (Drinkwater & Snapp, 2007; Savary, 2014; Tilman et al., 2001). As an unintended consequence, nitrogen, phosphorus and pesticides have caused water-body pollution, decreased biodiversity and contributed to climate change (Geiger et al., 2010; Hoang & Alauddin, 2010). The focus is now geared towards the need for more environmentally sustainable practices, to sustain and regenerate natural resources and the health benefits for the resilience of nature and people (Black et al., 2021, UNU-IAS & IGES, 2018). Whilst other factors such as economics are of importance for resilience, the environment is also intrinsic to it through resources such as healthy soil. Despite European policies aimed at enhancing environmental sustainability, such as agri-environment schemes, farmers have struggled to put more environmentally sustainable practices in place.

Since the rise of chemical and industrial agriculture, a spectrum of farming systems and related practices have emerged, from which Therond et al. (2017) have usefully created a contextual framework. It distinguishes three biotechnical categories: 'chemical input-based',

https://doi.org/10.1017/9781009093569.006 Published online by Cambridge University Press

'biological-input based' and 'biodiversity input-based'. The first includes only a few crops or a monoculture to which external chemical inputs are usually applied. Farmers try to make input use as efficient as possible, whilst adding other elements to the land only through regulatory bodies imposing this upon them. This often leads to low environmental sustainability, although efficient use may limit environmental impacts (Jägermeyr et al., 2015; Mueller et al., 2012). The second system also uses monocultures, or short crop rotations, and enforced landscape elements; however, as much as possible it incorporates biologically based inputs such as manure. The final 'biodiversity-based' system has a diversified crop sequence, voluntary landscape elements for wildlife, integration of livestock for fertiliser and aims to reduce external inputs (Therond et al., 2017). This system is often considered to have greater environmental sustainability, although in many conventional systems inputs need to be sufficient to avoid degradation (Aarts, 2016; Rosset & Altieri, 1997). Encompassing these farm types, Therond et al. describe the socio-economic systems that may surround them. 'Global commodity-based systems' aim to increase production and efficiency using standardised processes, leading to global competition, with power usually centred within global corporations. 'Circular economies' aim to reduce waste with closed resource loops, therefore giving farmers more control and autonomy. 'Alternative food systems' aim to create locally specialised values-based products using short supply chains. Again, this gives farmers more autonomy, whilst supporting biodiversity. 'Integrated landscape approaches' span local–regional scales and require cooperation between landowners, who work together to develop diverse, multi-functional landscapes spanning the food–non-food–natural resource nexus. There is variability within these categories, meaning that different farming systems may be at different positions within, for example, 'chemical input-based', as we explore through our case studies in the chapter.

The environment underlies resource availability, the processing of societal waste (such as CO_2 and water purification) and therefore a suitable climate to grow in, which in turn affects the economy and societal issues. Systems with low environmental sustainability lack or undermine resilience in the long term, and could be vulnerable to collapse (Meuwissen et al., 2019). This is especially the case when anthropogenic inputs put pressure on resilience (Rist et al., 2014) and environmental feedback signals are subdued through long-distance producer–consumer connections (Rist et al., 2014; Sundkvist et al., 2005). It is therefore important to improve the resilience of farming systems to ensure the provision of both public and private goods in the face of multi-faceted and increasingly complex pressures, through their robustness, adaptability and transformability (Meuwissen et al., 2019).

In order to improve farming system resilience across Europe, the predominant chemical-based agriculture within the global commodity system needs to readdress its reliance on both chemicals and global trade (Willett et al., 2019). Whilst global trade is important for businesses, diverse diets and inter-country relationships, an overreliance on it can be economically crippling when other countries are able to produce and sell for less money, pushing profits down. Better utilising and regenerating local resources whilst creating stronger links to local and regional socio-economic systems will establish greater balance and diversity in the system, enhancing sustainability and resilience (Duru et al., 2015; Willett et al., 2019). In 2020, the EU released its 'Farm to Fork Strategy', the first to encompass the whole food system (European Union, 2020). In order to achieve its goals, the inadequacies of previous agri-environment schemes and the barriers to adopting more environmentally sustainable production will need to be addressed (Arnott et al., 2019).

The three systems described in Therond et al. (2017) each constitute 'socio-technical regimes' and these regimes have structural rules that guide, in this case, farmers' perceptions and actions, otherwise known as social and cultural lock-ins (Burton and Farstad, 2020). The chemical-based system, for example, has created a 'lock-in', which means it is perceived as unworthwhile by farmers to change current practices that may be more environmentally sustainable (Plumecocq et al., 2018). A range of studies on lock-in have shown that it is complex and occurs across multiple farming sectors. For example, institutional lock-in through policies and selective agronomic advice incentivising yield; cultural lock-in through historic social events related to agricultural products and social lock-in through the need for family farm continuity (Beudou et al., 2017; Glover, 2014; Vanloqueren & Baret, 2008; Weis, 2008). Burton and Farstad (2020) stress that lock-in does not mean agricultural systems are unchanging, but that change is geared towards creating stability for the current system, as opposed to challenging it.

5.2 Aim of This Chapter

While other chapters focus more upon economic and production factors and their contribution to resilience, this chapter focuses on environmental sustainability and its inherent importance to resilience. Using Therond *et al.*'s farming system classification framework and the theory of lock-in in agricultural systems, we assess the environmental sustainability and therefore resilience of three case studies within Europe. We demonstrate how the challenges they face lock them in to their current systems, despite EU policies geared towards agri-environment schemes. With multi-stakeholder input, we then show how tackling these lock-in factors can create more sustainable and resilient systems.

5.3 Research Methods

We use three case studies (CS), namely (i) extensive ovine breeding in Huesca (Spain), (ii) hazelnut production in Lazio (Italy) and (iii) arable farming in the East of England (UK).[1] These three CS cover livestock, perennial and arable farming sectors, which are experiencing a heterogeneous range of challenges to resilience. In each CS, researchers in their respective countries identified the baseline information about the current farming systems through interviews and grey literature. Using this baseline information to assess against Therond et al.'s (2017) framework on farming system model diversities, we classify the current CS farming systems in order to understand the environmental sustainability and resilience of each.

The information used to outline the challenges and potential future systems to tackle these comes from workshops held as part of the SURE-Farm project across the three CS (Paas et al., 2019, 2020; Reidsma et al., 2020a). These workshops consisted of different types of stakeholders (researchers, farmers, policy makers and NGOs) of the farming system in the CS regions. The workshops identified multi-stakeholder perspectives and knowledge on the current challenges faced in each CS as well as creating strategies for alternative systems with improved sustainability and resilience (Reidsma et al., 2020a).

[1] The reader is referred to Chapters 9, 11 and 16, which specifically describe in detail the case studies of Spain, Italy and the UK, respectively.

https://doi.org/10.1017/9781009093569.006 Published online by Cambridge University Press

From the challenges, the authors of this chapter have identified how they create lock-in conditions across multiple factors (e.g. social, institutional, economic and cultural) for farmers and other actors in each CS. For example, social trends towards eating less lamb have impacted the Spanish CS, lowering profits and pushing some farmers towards stabled intensive methods or an abandonment of farming, and, therefore, also having potential unintended environmental consequences. The future scenarios included what the multi-stakeholder's thought could be possible in a scenario where challenges (and therefore lock-in conditions) were actively tackled.

5.4 Placing Current Systems within a Biotechnical and Socio-economic Framework

Here, each CS is summarised and placed within Therond et al.'s spectrum of possible biotechnical and socio-economic systems (see Figure 5.1).

Extensive ovine breeding in Huesca, Spain – biological input-based, global commodity system:
The Spanish CS consists of extensive ovine breeding oriented to lamb production and is located in the Province of Huesca, Aragón. Most of the agricultural practices take place in the mountain foothills and on the lower plains, with traditional environmentally sustainable transhumance practices, when herds do not exceed the natural resources (Navarro, 1992). Grazing preserves the grasslands, which may otherwise undergo encroachment from shrubs and trees, lowering biodiversity (Bernués et al., 2005; Peco et al., 2017). Livestock are largely fed on grasslands; however, some straw feed is bought in externally, more so in lowland areas where less land is available. The ovine sector was a strong economic contributor to the region; however, its importance has declined heavily in the last twenty years, moving to intensive stabled or semi-stabled rearing (Fau, 2016). Whilst the main markets have traditionally been local (regional and national), changing preferences towards meats with a milder taste, which are easier to cook and cheaper (Mandolesi et al., 2020) mean that the products are increasingly supplied into the globalised market system, particularly to Islamic countries (Alcalde et al., 2013; MAPA, 2019). To cope with the decreasing popularity of sheep meat, new sales initiatives have been established such as the Protected Geographical Indication (PGI) label,

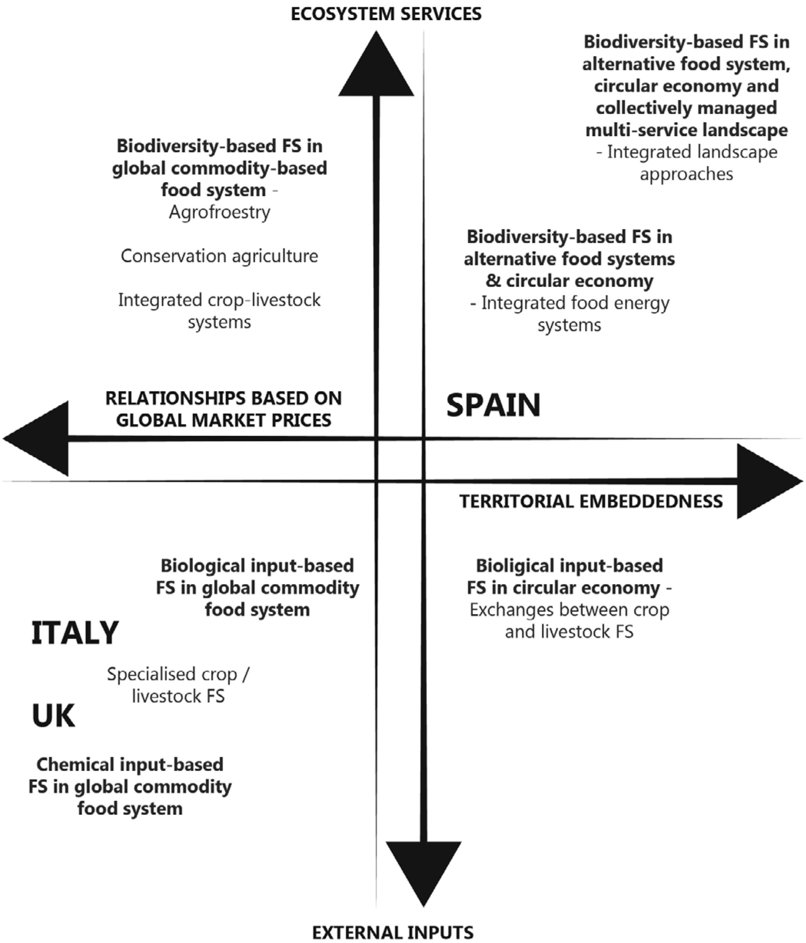

Figure 5.1 Position of the three European CS agricultural systems on Therond et al.'s biotechnical and socio-economic framework
(adapted from Therond et al., 2017).

'Ternasco de Aragon'. This label can include both outdoor, extensively reared lamb and stabled lamb (Sans et al., 1999), and is used by ~30 per cent of the farms in the CS region (Spiegel et al., 2019). Typically, family-based small (<100 sheep), medium (100–499 sheep) and large (>500 sheep) farms of equal representation exist (Aragon.es, 2019). Performance of economic, social and environmental system functions is perceived to be low by stakeholders in the CS

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(Reidsma et al., 2020b). This perception indicates that more change is needed at the CS in order to increase the performance of the system and its resilience. The farms' reliance on financial public aids could enhance the system's robustness (while constraining the other capacities), but the excessive dependence on subsidies poses a challenge for robustness in the future. Further, the intensification process includes specialization and industrialization, which can strengthen robustness but somewhat constrain adaptability and transformability (see also Hoekstra et al., 2018). Innovations in the pasture and flock management and feeding systems, as well as new farmers' organizations to improve sales and knowledge exchange, may promote the system's adaptability. However, these processes are rather recent, and their overall effect needs to be assessed. Except for some degree of diversification, there appears to be no transformability towards desired change in the farming system. In general, the resilience relies on robustness and adaptability that, in turn, appear weak and relate largely to the economic performance and less so to the social or environmental, which creates a bias and may undermine resilience. According to Meuwissen et al.'s (2019) framework, resilience is therefore low.

Hazelnut production in Viterbo, Italy – chemical input-based global commodity system:
In Viterbo province, central Italy, the cultivation of hazelnut trees (*Corylus avellana*) goes back several decades. In 2018 production reached 46,200 tons on 23,000 ha (ISTAT). Hazelnut production in the area values on average 70–80 million €/year, and is a major income source. Specialization started in the 1960s due to hazelnuts being a convenient cropping system here. Previously, hazelnuts used to be cultivated alongside other species (e.g. olives, vines, chestnuts). In the last decades, increased demand from the confectionary industry has led to price growth, specialisation and expansion (Bijttebier et al., 2018). The landscape has gone through a profound change, with large parts of the farming system now dominated by hazelnut monocultures. Farm sizes are predominantly small (<10 ha) and based mostly on family labour (Bijttebier et al., 2018). Chemicals such as pesticides are widely used, with organic production limited as it is less profitable (Coppola et al., 2020). Farmers maintain that chemical use is not particularly high in this farming system. Despite this, local opposition (e.g. civil society and environmental groups), have voiced concerns to municipal authorities. This has had limited success, with restrictions only on

some chemicals close to residential areas, partly because legal chemicals cannot be prohibited by municipalities. Although chemicals are used, some hazelnut farmers use a Designation of Origin (PDO) label. However, as most farms send hazelnuts to large multinational corporations for processing, most do not use the PDO label with which local processing is required. Food production and economic viability is perceived to be good, while the level of maintenance of natural resources is perceived to be low to moderate according to farming system stakeholders (Reidsma et al., 2020b). As in the previous CS, a level of robustness is seen through the ability of the farming system to withstand changes described over the last several decades, whilst adaptability has further been demonstrated through intensifying hazelnut production. Transformability of this farming system has not been evidenced. However, whilst the current economic resilience may be good, environmental resilience is low and may therefore undermine longer-term overall resilience (economic, environmental and social) through resource depletion, such as underground water. A long-term view of economic resilience is usually considered by farmers with perennial crops such as trees, as they are productive for thirty years or more. Therefore, environmental resilience is an important consideration, especially when these crops are less ‘flexible’ in making changes because of their life span and initially high set-up costs for such systems. The economic resilience also depends upon the changing pressure of global markets and is uncertain. This uncertainty stems from the disconnect between farmers and multinational corporations, who dictate prices makes future economic resilience a challenge.

Arable production in East Anglia, UK – chemical input-based global commodity system:
The case study of the UK is in the East of England where intensive arable agriculture using chemicals and short crop rotations prevail on fertile soils, which results in high production capacity (Bijttebier et al., 2018). This region is responsible for one third of the country’s cereal production, consisting mainly of wheat and barley. The farms are mostly large-scale family or corporate; in the last ten years the size of the farms grew considerably whilst their numbers decreased by more than 40 per cent, yet farmland surface area remained the same (Bijttebier et al., 2018). Product prices are influenced by globalised food systems (Reidsma et al., 2020a; Vigani et al., 2020). A small number of farmers use livestock for manure, reduced ploughing and

https://doi.org/10.1017/9781009093569.006 Published online by Cambridge University Press

grow cover crops. This is because environmental awareness of agricultural impacts and public goods develops alongside increased chemical regulations. Performance levels of economic, environmental and social system functions – which indicate system sustainability – are perceived by stakeholders to be moderate, suggesting that improvement is indeed required (Reidsma et al., 2020b). A level of robustness is apparent from the ability of the farming system to withstand pressures of product prices from the global market without collapse; however, the amalgamation of farms (increased farm size) suggests that some have collapsed. Robustness is therefore variable across farms, but likely low. It is evident from some of the remaining farms that they have been able to adapt to resource and regulatory pressures by, for example, incorporating cover crops and livestock. These are incremental changes, however, and again transformation of the system is not apparent in this CS. As stakeholders allude to, greater resilience needs to be developed across the environmental, social and economic functions of the farming systems.

5.4.1 Analysis

Two of the CS (Italy and the UK) reside in the bottom-left corner of the framework, highlighting intensive practices and the global market influence on them. Spain, however, sits in the top right corner (biodiversity-based, territorially embedded food system), but is being pulled towards the bottom left (biologically based, global commodity food system) by current pressures, hence it is near the intersection of these two different systems. Despite Italy and the UK being in the same category, there are nuances between them which set them apart within the category itself. In the UK, whilst there are some farmers starting to use biologically based inputs, the overall system is dominated by chemical inputs. Italy differs in that whilst chemicals are used, the levels of use are not high and the perennial crops mean that there is more biological input, e.g. leaf litter, aiding carbon sequestration as well as nutrient input (Fireman, 2019). The CS in Spain is based on largely local and biological inputs and contributes to biodiversity through extensive grazing; however, recent trends are pulling local sales towards international markets and their resulting influence, such as using more intensive methods like stabling. It is therefore apparent that all three systems require substantial changes to tackle their challenges and move towards greater environmental sustainability; out of the bottom-left corner to the top-right corner of Figure 5.1. The challenges are outlined next, from which we illustrate how they are 'locked-in' to their current practices.

5.5 Challenges and Lock-Ins to Current Agricultural Systems

The three CS each have a range of challenges associated with low environmental sustainability. In Table 5.1, these challenges and their associated lock-in factors are presented. In the following section, these challenges and potential solutions are discussed.

Economic lock-ins are particularly complex, evidenced by apparent contradictions between the CS countries in the table (i.e. both low and high profitability can cause poor environmental sustainability, affecting resilience) and are therefore worthy of greater explanation here. In Spain the decreasing lamb consumption within the region and nationally – where most of the product is sold – is a key lock-in factor as it decreases profits and economic viability. With the Spanish CS region now moving into the global market for income, it has had to intensify production through stabling sheep, due to increasing competition both nationally and internationally, therefore reducing environmental sustainability and resilience. Similarly, the UK CS farmers are economically restricted through the global market, again creating competition that drives arable crop prices down, resulting in intensification of crop production. Both these CS are therefore constrained by low profitability, restricting their ability to undertake environmentally sustainable production options. In Italy, economic stability is currently provided by selling high-quality hazelnuts into the global market, as potential competition from other production regions, such as Turkey, has not yet caused an economic problem. However, interestingly, in opposition to the Spanish and UK CS, where low profits are constricting environmental efforts, the economic stability prevents farmers from considering more environmentally sustainable practices such as no chemical use/organic methods. This is because the quality of produce needed to sell into the global markets is associated with low pests and diseases – for which chemicals are used. These chemicals may bioaccumulate in the environment over time and cause problems to the surrounding ecosystem and health of the local population. Such economic lock-ins are, however, only part of the picture, as Table 5.1 demonstrates.

Table 5.1. *Challenges and lock-ins to the three CS systems*

		Economic	Social	Cultural	Institutional
Spain	**Challenge**	Decreasing demand for lamb meat; increasing feeding costs	Out-migration of people from rural areas due to poor perception of lifestyle quality; land abandonment	New consumers' preferences alongside social media causes the perception of meat to be distorted	Lack of government support to continue pastoral farming; poor access to pastures and information on the benefits of rural living
	Lock-in	Low profit creates an inability to invest in sustainable methods	Lack of labour and new farmers to progress the farming system and implement on-farm changes	Compounds economic lock-in through lack of sales and low profit margins	Using fewer pastures increases intensive practices, whilst poor support for continuation is compounded by economic and social challenges, creating lower capacity to progress sustainable practices
Italy	**Challenge**	International markets provide profit and favour intensive production, as opposed to local markets	Increasing need for high hazelnut quality; out-migration of people from rural areas	Growing opposition within civil society to the hazelnut monocultures and to the spread of new plantations in the area	Instability from CAP changes; poor knowledge exchange support to change practices; local R&D hazelnut-focused Local Action Group (LAG) supports current practices

	Lock-in	Economies of scale, profits and favourable land values prevent the search for alternatives	Strong interdependencies between different FS actors creates difficulty in changing practices	Local annual cultural events create a feeling of identity with hazelnuts among the population	Instability and low knowledge make it difficult to change practices; R&D focused on single crop rather than diversity; LAG promotes system stability
UK	**Challenge**	Global price competition; lack of economic support to change practices; risk of post-Brexit subsidy loss	Out-migration of people from rural areas	Farmers' perception of fields looking 'neat'; fear of failure in alternative practices; growing public environmental awareness	Lack of advice on sustainable practices or innovation; lack of support through transitions; uncertainty of Brexit; short-term tenancies; landowners hold power in management decisions
	Lock-in	Decreasing prices and profit margins cause further intensification	Lack of labour and new farmers to progress the farming system	Prevents transition to alternative practices; inadvertent public pressure could prevent integrating livestock	Prevents farmers from transitioning to or learning about more sustainable and resilient farming practices

All challenges are compounded by the lack of overarching government support regarding financial aid in transitioning practices, providing independent and coherent advice, accessing knowledge exchange and encouraging future generations to farm. This is despite EU and national government agri-environment schemes, which have failed to give such holistic support (Arnott et al., 2019). In addition to these challenges, the environment externally influences the CS through increased droughts, wild fauna attacks and pathogens (Reidsma et al., 2020a).

As the individual lock-ins compound each other, it is apparent that they collectively hold, or pull, the CS to the lower-left corner of Therond et al.'s diagram (specialised crops or livestock in a global commodity food system). Therefore, they need to be addressed collectively, which necessitates substantial changes and thus positive transformation to the upper-right corner of Therond et al.'s diagram (biodiversity-based, circular landscape-scale food systems).

There are some signs of the lock-ins beginning to be broken open in each CS, however, which are described in the following section. Strategies to better develop and add to these break through mechanisms, as discussed in multi-stakeholder workshops, are also discussed below.

5.5.1 Towards More Environmentally Sustainable Systems

Future systems, which were envisioned in stakeholder workshops, in order to tackle these challenges are equally unique, but also have some common themes. In Spain and Italy, where public environmental awareness is perceived to give strong feedback signals to farming systems, valorising environmentally sustainable products and practices for local markets and consumers through awareness raising and advertising is likely to be central to any strategy. Indeed, Kneafsey et al. (2013) set out the importance of short supply chains in Europe towards greater social and environmental impacts and the need for them to be better supported by public policy. In Spain, particular attention is needed to address the poor public understanding of ecosystem diversity and value of extensive sheep farming. Alongside access to land and wild fauna attacks, this has added to farmers in the CS region feeling that the main viable option is to become more intensive in production and take on global market opportunities. Stakeholders envision that increasing the publics' knowledge and understanding of the intricacies of the system will help provide support to farmers, making their local and regional markets more robust and adaptable, whilst diversifying markets. Such a strategy begins to break a developing lock-in: the movement towards a reliance on global markets (and therefore the pull towards the lower left corner of Therond et al.'s diagram). This will need investment and support from government in educating, creating routes to market and training. The PGI label given to some lamb meat may also help to improve consumers' perceptions of it. Along with the new CAP reform post-2020, there is also room for delivering tailored support for the environmental benefits provided by extensive sheep farms, mainly within the framing of the Eco-schemes.

In Italy, stakeholders suggest that local processing of hazelnuts and diversifying of monocultures will be an important element for a shift towards greater environmental sustainability. Likewise, local processing and direct selling could then increase employment and incomes while shorter supply chains will also positively impact the environment. Stakeholders also think that this may attract younger generations, who have a greater propensity to organic farming. Such actions are likely to have a positive impact upon the robustness and adaptability elements of resilience through diversifying away from one market avenue and having more participatory actors directly involved with the running of the system. As in Spain, this would begin to break some of the economical lock-in to the lower left of Therond et al.'s diagram. However, investment will be needed to develop local markets, processing facilities and potentially training depending upon skill levels. Governments therefore need to encourage hazelnut companies to invest some of their own profits into this, or provide funding itself. Van Ittersum et al. (2007) and a recent European survey (Kantar, 2020) showed that European consumers have an awareness of PGI (20 per cent of respondents) and PDO (14 per cent of respondents) labels and place importance when buying produce upon high-quality (81 per cent of respondents) locally produced foods (87 per cent of respondents), including organic (56 per cent of respondents), of which awareness has generally increased since 2017. This appreciation of labels and organic could potentially help create more market opportunities in these regions (Kneafsey et al., 2008). Due to consumers placing importance on these types of production, care and transparency will be needed in building consumer trust, as current agricultural practices that are permitted within these labels include indoor rearing and chemical use. Public mistrust and confusion could be alleviated by redefining the production practices to align with environmentally sustainable methods, such as organic and lamb feed sourced only from local hay, for example.

In the UK, workshop stakeholders agreed that greater institutional support is needed through government payments such as public money for public goods (Bateman & Balmford, 2018; Food Farming and Countryside Commission, 2019). This may be realised through the new Environment Land Management Scheme (ELMS). ELMS has, to date, indicated three levels of agricultural management: farm-scale, farm clusters and a wider landscape scale across England. Bringing together farmers and landowners in groups, whilst working with existing groups, aims to manage the landscape more holistically. However, at the time of writing, this is subject to being jeopardised by international free trade agreements allowing imports of cheaper produce grown to lower environmental sustainability standards (DEFRA, 2020; Vigani et al., 2020). These changes to agricultural policy, which are currently under planning, indicate that ways to address lock-ins are being considered. However, careful consideration and comparison to other policies such as trade, which may slow or reverse positive progress, is required. Stakeholders further discussed that a 'volatility payment' may also be needed to support farmers through a transition period where yields may suffer due to changing soil conditions (Vigani et al., 2020). Farmers who are already tackling lock-ins to chemical use through green manures and cover crops, for example, could be better supported and connected for knowledge transfer, therefore spreading these practices. Improving knowledge exchange and transition support could further aid change through implementing practices which actively encourage biodiversity and regeneration of natural resources. Given the unique context of tenure in UK agriculture, stakeholders considered that well mediated, transparent three-way conversations between tenants, land owners and government may be needed to address challenges of land owners making unsustainable management decisions (Vigani et al., 2020).

Alongside these socio-economic changes, stakeholders have voiced the need for technology to be better developed. In Spain, this takes the form of geo-location and surveillance of sheep and wild fauna, and in Italy through processing plants, efficient irrigation and auto-propelled harvesting machines (Reidsma et al., 2020a). Brauman et al. (2013) have demonstrated how gains in agricultural efficiency, whilst reducing waste and changing diets, can benefit the environment. Such practices can enhance resilience through ensuring a more robust (plentiful or regenerative) supply of natural resources. In Italy, there is already a rather high technological level, which contributes to its competition on the global markets. However, the prospect of further developing such technologies is thought to be attractive to the younger generation, who are able to improve technical and organizational innovation in the sector. In the UK, farming stakeholders envision having a greater ability to feed into technological innovation through partnerships with researchers and industry. For instance, farmer-led innovation is gaining traction, and their participation in new technology can lead to further innovation and more effective use of equipment or practices (Ingram, 2010; Reed et al., 2017). Engaging farmers with advisory services and building trust can lead to greater learning and a willingness to undertake more environmental practices (Mills et al., 2017). Such technology could also aid environmental sustainability, through water conservation and a more efficient use of fertilisers (Brauman et al., 2013; Smith et al., 2014; Tilman et al., 2011). Farmer-led technology allows for greater resilience through empowering the end-user to create connections with a range of stakeholders and plan what technology would increase their farm robustness and adaptability across environmental, social and economic fora. However, while infrastructure for innovation is needed for transformability, strategies implemented in the past (e.g. mechanization in Italy) were often seen as constraining transformability (Reidsma et al., 2020b). The type of technology is important, and path dependency needs to be avoided. Well-considered technological innovation could tackle economic and social lock-ins, where farmers need not be reliant on tech companies, and younger generations are attracted by positive opportunities to innovate.

In all three CS, stakeholders discussed the need for better facilitating cooperation amongst farmers and other actors to help foster knowledge exchange and sense of community (Reidsma et al., 2020a). Such cooperation could engender greater resilience through increasing the knowledge of stakeholders and strengthening their networks for communication, thereby providing robustness across multiple actors and the ability to adapt by transferring knowledge. In Spain, increasing cooperation between farmers is opening up opportunities to align the traditional extensive sheep farming supply with the changing consumer preferences, by creating new high-quality lamb meat products and emphasising their value to ecology. Fostering cooperation can help tackle the institutional lock-in of poor knowledge exchange. As ideas and knowledge grow, such networks may also develop the capacity to transform the system if actors feel this is needed. In the UK, the creation of more farmer groups will help effectively reach isolated farmers and create a supportive base for knowledge exchange on alternative sustainable practices – whilst also tackling social lock-in issues, such as maintaining 'neat' fields. The base of existing groups and 'demonstration farms' which help farmers to address agricultural issues such as declining soil conditions can be built on and improved. In Italy stakeholders suggest that challenging farmer learning, knowledge exchange and financial aid through agri-environment schemes is likely to be important, which in turn has implications for the design and delivery of such schemes.

On a national and European scale, the strategies outlined by the stakeholders of each CS – if implemented well – could positively contribute towards the EU's 'Farm to Fork Strategy' and international Sustainable Development Goals. However, each strategy separately will not help substantially tackle the overall lock-in: the lock-ins feed into each other and therefore an individual strategy to address one will eventually be constrained by another. For example, fostering greater cooperation can break institutional lock-in by empowering farmers with knowledge to produce in more sustainable ways, but support is then needed economically to allow for the creation of new local market avenues. Separately, they can only make small, incremental changes to the system, which aids robustness and adaptability to an extent, but does not allow for holistic transformation to a desired system which would engender greater overall resilience. The CS farming systems are either dependent on global market prices and external inputs, and therefore positioned at the bottom-left of the framework of Therond et al., or pulled towards that direction (the system in Spain). Transformation towards the upper-left requires government support to improve agricultural practices (including cover crops, crop diversity, biodiversity and wider landscape management), develop local markets and processing, improve the understanding and perception of the public about good agricultural practices, invest in appropriate technology and facilitate cooperation among farmers and other actors. Therefore, government support must not put agricultural policy and support in a separate silo, as agricultural practices are also dependent upon trade policies, research and development priorities and public health policies (Willett et al., 2019). A vicious cycle can only be changed to a virtuous cycle when all these strategies are addressed, and when policies that limit their implementation, such as trade policies, are addressed.

5.6 Conclusions

This assessment of three European CS in diverse farming sectors has highlighted that exposure to global market prices, reliance on external inputs and pathways of intensification (productivism) have created low environmental sustainability and resilience across all of them. Many of the challenges therefore cross all three sectors and agricultural systems, including low profitability, failing governmental support, climate change and public pressure for more environmental practices. Together, these cause a lock-in, and single strategies are not enough for a transformation towards more desirable, sustainable systems.

An enabling environment for each CS, and for wider European farming systems, is needed to move towards greater environmental sustainability and resilience in their agricultural practices. Government support needs to tackle the multi-faceted and compounding sets of factors that create lock-in, which will require a strategic and systematic plan through policy and multi-stakeholder input and collaboration. At present, institutional arrangements introduce measures to improve environmental sustainability but do so without challenging or contradicting the rules that underpin the system (i.e. change *within* the socio-technical regime). A greater appreciation of lock-in is therefore essential in agricultural policy, because overcoming structural rules that constrain environmentally sustainable agricultural practices in farming systems is difficult.

Before sustainable practices can be realised on the ground, the social and cultural context of farming systems needs to be understood and institutional and structural barriers need to be overcome. Whilst farmers are locked-in to ever-decreasing profit margins in the global market, decreasing natural resources and complex environmental issues, policy needs to be agile enough to support them through various sustainability transitions. Such policy support would be with a view to long-term saving both financially and environmentally as soil health, water availability and biodiversity re-establish. Such an overall strategy for transformation of the farming systems would also create a more supportive social and cultural basis for transitioning farmers, whilst attracting new entrants to farming.

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