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Sustainable Development and Pathways for Food Ecosystems

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Chapter 6

Sustaining biodiversity and ecosystem services with agricultural production

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6.1 Introduction: farming in the Anthropocene

Agricultural systems are essential for our food security, well-being, and health. Undoubtedly, agriculture has fostered the growth and prosperity of our societies. Since it first appeared in the Neolithic, agriculture has spread over the global surface modifying and disrupting the structure and functioning of the native ecosystems, giving rise to what we know as agroecosystems. They also embrace a community of plants and animals interacting with each other and the physical environment. But, unlike native ecosystems, most of these communities are planned and selected by humans to produce food, fiber, and fuel (Muscat et al., 2020).

Currently, agroecosystems occupy approximately 40% of the global land surface, being one of the largest terrestrial biomes on the planet (Foley et al., 2005; Mottet et al., 2017; Poore & Nemecek, 2018). Of this land, about one-third is cropland and the remaining two-thirds are meadows and pastures for grazing livestock (Mottet et al., 2017). Agroecosystems consume 70% of freshwater (World Water Assessment Programme, 2012), and they are responsible for a large share of the total net anthropogenic emissions of greenhouse gases (estimated between 14% and 28% according to IPCC, 2019). The impact of agriculture is currently considered one of the major drivers of global change (Campbell et al., 2017). The current expansion and development of agroecosystems are modifying the N, P, and water cycles at the global scale, exacerbating climate change, and accelerating the rate of biodiversity loss, threatening the

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well-functioning and resilience of our Earth system (Campbell et al., 2017; Rockström et al., 2009; Steffen et al., 2015).

The developments in agriculture over millennia, however, have led to a huge variety of agroecosystems worldwide. Agroecosystems, therefore, have developed particular ecological structures and functioning, and context-specific relationships with the surrounding natural ecosystems. This leads to wonder whether the effects of agriculture on biodiversity and ecosystem services are the same in all agroecosystems and across ecoregions; or whether the goals of producing food and conserving nature are so irreconcilable. This chapter aims to delve into these questions. Before that, however, we need to reflect on the main changes in agroecosystems that have led to biodiversity loss and deteriorated ecosystem services.

From the end of the 19th century, technological development in agriculture allowed incipient intensification and specialization in farming systems. After World War II, and particularly since the middle of the 20th century, the processes of intensification and specialization were strongly encouraged through agricultural policies to increase food production, the widespread implementation of technological innovations, and the contribution of the financial systems (Ripoll-Bosch & Schoenmaker, 2022). Four interrelated processes define the main trends observed to date (Fig. 6.1): (1) the intensification of farming systems through the increasing use of natural and artificial inputs, (2) their specialization, decoupling traditional mixed crop-livestock farming systems and promoting monocultures, (3) the decrease in the number of farm holdings, and (4) the enlargement of the farm holdings. These trends, while successful in increasing overall food production, are also causing a decline in biodiversity and deteriorating a range of ecosystem services delivered by agroecosystems because of the simplification and homogenization of agricultural landscapes and the abandonment of low-input agricultural systems (hereafter referred as traditional agroecosystems) associated with high nature value (HNV) farmlands (e.g., mountains, *dehesa* and *montado* pastures) (Henle et al., 2008; Tscharntke et al., 2005). Domestic and wildlife biodiversity has evolved together over millennia and integrated into these traditional agroecosystems (Velado-Alonso et al., 2020a). Therefore, the disappearance of these agroecosystems could also lead inevitably to the loss of both wildlife and domesticated species biodiversity and the decoupling of native livestock breeds and plant species from the environment where they evolved (Velado-Alonso et al., 2020b).

To better understand these historical trends, we must see agroecosystems as complex social-ecological systems (Fig. 6.2), where social, economic, institutional, and ecological factors interact at different scales over time (Berkes & Folke, 1998). The social-ecological framework allows the operationalization of the ecosystem services concept in real-world conditions, by linking agroecosystems, farming and forestry systems, management practices, value chains, societal expectations, and policy. Here, farming can be considered as an intermediary element that modulates the "natural flow" of ecosystem services from nature

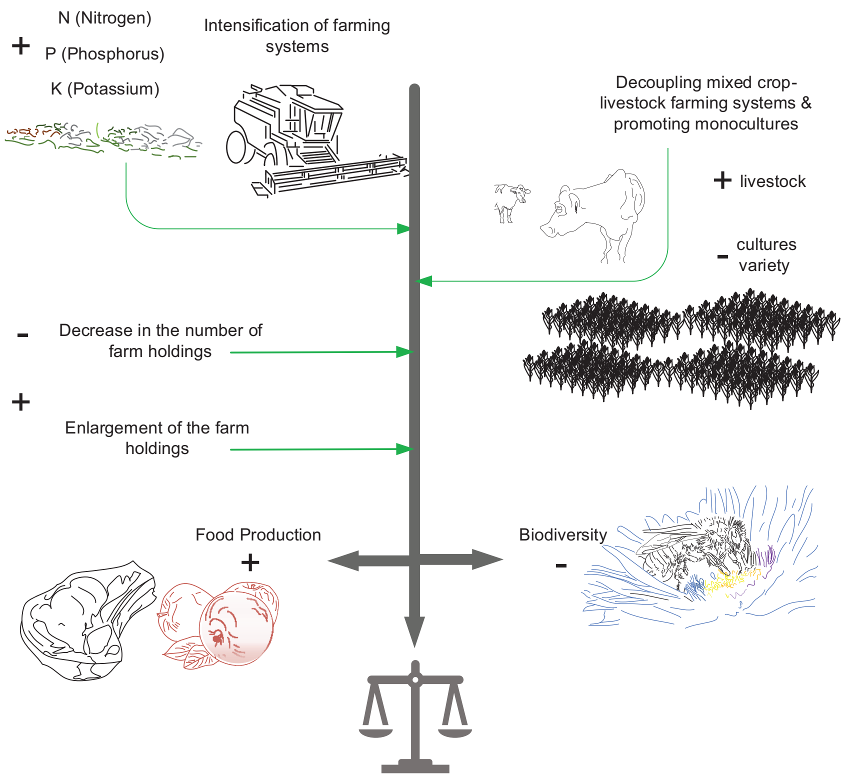

FIGURE 6.1 Trends, pathways, and consequences of technological development in agriculture.

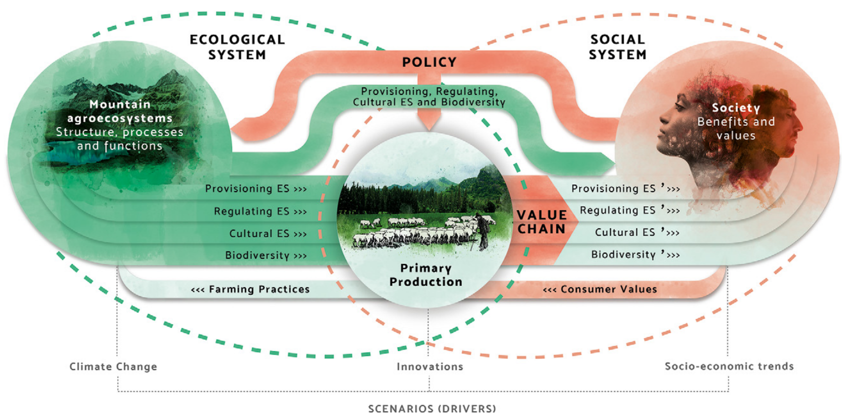

FIGURE 6.2 Agroecosystems as complex social-ecological systems. Our societies define the characteristics of the agricultural systems through values and demands, policies and regulations. In turn, this determines the specific farming practices that eventually modify the structure and functioning of agroecosystems and, therefore, the public and private goods that agricultural systems provide to our societies (*Source:* Adapted from Martin-Collado et al. (2019)).

to people. This framework has the potential to integrate, with the same level of priority, the provisioning services (mostly private goods like meat, milk, or wood) and the regulating and cultural services (mostly public goods like water regulation and aesthetic value of the landscape) and biodiversity. This allows integration into the analyses of the multiple trade-offs and synergies that can exist between primary production value chains and the long-term provision of public goods.

This complex systems-thinking framework fosters the integration of biological, economic, and social disciplines. Hence, it considers the biophysical, socio-economic, and governance context in which the limitations to primary production and ecosystem conservation occur. Therefore, the knowledge generated through this framework of analysis needs to be disaggregated by different agroecosystems and production systems, which can differ widely in land use, resource efficiency, production levels, and environmental outcomes.

Thus, we must see agroecosystems like dynamic systems that change through time, adapting to the socioeconomic and environmental context. In the Anthropocene, climate change will negatively affect agricultural productivity in most world regions, and with a growing human population, among other drivers of global change, we have a great challenge ahead of us. We must steer our agricultural systems into agroecosystems that minimize their impact on the Earth System while guaranteeing enough food production for the current and future generations. We still have a chance to rethink and reorient agroecosystems, reconciling food production in quantity and quality with the maintenance of biodiversity and ecosystem services.

In this chapter, we first explore the complex relationship between agricultural production, biodiversity, and ecosystem services. Second, we present some examples of livestock farming systems that constitute potential seeds for change. Finally, we reflect on the effects that we as citizens and consumers, and the agricultural policies could have on the future of our agroecosystems, and therefore, on biodiversity and ecosystem services.

6.2 The complex relationship between agricultural production and biodiversity and ecosystem services conservation

As explained above, there is wide agreement that the current widespread agricultural model has a negative impact on biodiversity and the wide provision of ecosystem services. However, the relationship between ever-evolving agroecosystems, biodiversity, and ecosystem services is far more complex.

Biodiversity and ecosystem functions and services are interrelated concepts embodied in the wider notion of nature (IPBES, 2019; see Box 6.1 for further information on definitions). Biodiversity and ecosystem services have a multilayered relationship at all levels of the ecosystem services framework hierarchy

(Mace et al., 2012). Hence, it is generally assumed that high levels of biodiversity relate to increased delivery of ecosystem services and functions, and a higher level of well-being in people. However, equating biodiversity to ecosystem services (and vice versa) is controversial, particularly when it comes to metrics, values, and management interventions for conservation and enhancement (Reyers et al., 2012).

BOX 6.1 Definitions of nature, biodiversity, and ecosystems services

Nature is a broad concept that can encompass categories such as biodiversity, ecosystems (structures, functions, and services), biosphere or evolution, and humankind's evolutionary heritage, along with other notions such as "Mother Earth" (IPBES, 2022).

Biodiversity is understood as the "variability among living organisms [...], including diversity within species, between species, and of ecosystems" (CBD, 1992).

Ecosystem services are the direct or indirect benefits people obtain from (agro)ecosystems (MEA, 2005; TEEB, 2010; Zhang et al., 2007). The notion of ecosystem services and the ecosystem services framework became popular after the Millennium Ecosystem Assessment (MEA, 2005; Rodriguez-Ortega et al., 2014). The ecosystem services are generally classified into four categories: (1) Provisioning: products obtained from (e.g., food, timber, or water); (2) Regulating: regulation of ecosystem processes (e.g., pollination, regulation of climate, or water purification); (3) Cultural: non-material benefits (e.g., recreation, spiritual, or cultural values); and (4) Supporting: precondition and maintenance of other categories. The (MEA, 2005) extensively reported the relationships between ecosystem services and human well-being. The Economics of Ecosystems and Biodiversity (TEEB, 2010) aimed to report on the economic (monetary) value of ecosystem services across global biomes.

Then, the relationship between agroecosystems and biodiversity and the provision of ecosystem services is not straightforward, but rather complex, nonlinear, and multifaceted (Hooper et al., 2005; Kok et al., 2020a). Zhang et al. (2007) defined a four-way interaction in which biodiversity and ecosystem services can have positive, but also negative effects on agroecosystems; meanwhile, agroecosystems can also deliver positive or negative effects on biodiversity and ecosystem services. Indeed, agriculture and its sustained production are underpinned by biodiversities and ecosystem processes and services, such as pollination, pest control, or dung burial (Zhang et al., 2007). However, agricultural production can also be threatened by biodiversity, through the appearance and expansion of pests, diseases, and predators that affect both crop and livestock production (Hartel et al., 2019; Herd-Hoare & Shackleton, 2020; Morales-Reyes, et al., 2017; Schowalter et al., 2018). These negative impacts of ecosystem services on agriculture have often been referred to in the literature as disservices

(Schowalter et al., 2018; Zhang et al., 2007). The negative impact of agroecosystems on biodiversity can result in negative feedback loops and ultimately promote further disservices to agroecosystems (Schowalter et al., 2018; Zhang et al., 2007).

When it comes to the effects of agroecosystems on biodiversity and ecosystem services, these can also be either negative or positive. Regarding the negative effects, agriculture and the recent development trends (expansion and intensification, described above) are generally driving biodiversity loss. Biodiversity loss applies to domesticated species for agriculture and food production (FAO, 2015, 2019) as well as to wildlife biodiversity (Benton et al., 2021; IPBES, 2019). Within agroecosystems, local varieties and breeds of domesticated plants and animals are disappearing worldwide (FAO, 2019). This loss of diversity, including genetic diversity, poses a serious risk to global food security by undermining the resilience of many agricultural systems to threats such as pests, pathogens and climate change (FAO, 2019; IPBES, 2019).

Moreover, intensive production and practices can degrade soils and the ecological process therein, driving down the productive capacity of land and necessitating even more intensive food production to keep pace with demand (Benton et al., 2021). Beyond farmland, agriculture also threatens wildlife biodiversity and natural ecosystems through expansion (e.g., land use and land use change) and intensification (Maxwell et al., 2016; Newbold et al., 2015). This biodiversity loss has been reported for species (Hallmann et al., 2017; Stanton et al., 2018) and for the destruction of habitats and natural ecosystems (Barlow et al., 2016; Giam, 2017). Special mention should be made to the irreversible loss of pristine or well-conserved natural ecosystems due to farming systems expansion that is still taking place at alarming rates in many world regions (e.g., Estrada et al., 2018; Gaveau et al., 2019; Lourenconi et al., 2021).

Regarding the positive effects, on occasion, agriculture and livestock production can underpin and contribute to the delivery of ecosystem services and enhancement of biodiversity (Cooper et al., 2009; Kok et al., 2020a; Rodríguez-Ortega et al., 2014; Zhang et al., 2007). That is the case with traditional agroecosystems, particularly mixed crop-livestock, and pasture-based livestock farming systems (Cooper et al., 2009; Rodriguez-Ortega et al., 2014). These types of agroecosystems are, for instance, notable under HNV farmland. In Europe, HNV farmland is a concept that involves long-established, low-intensity, and often complex farming systems (Keenleyside et al., 2014) and is crucial for the conservation of biodiversity and meeting the growing demands for ecosystem services (Moran et al., 2021). However, other farming systems have the potential to support wildlife biodiversity at the local and regional scales, such as organic agriculture (Bengtsson et al., 2005), circular agriculture (Muscat et al., 2021a), agroecological approaches (Wezel et al., 2018), nature-inclusive farming (Runhaar, 2017) or agroforestry (Nerlich et al., 2013). Many of these farming systems are particularly important for the maintenance of arthropods' biodiversity and all the wildlife species that depend on them, which populations are also silently declining at alarming rates worldwide being habitat lost due to intensive agriculture expansion and agrochemical pollutants key drivers of the decline (e.g., Benton et al., 2002; Habel et al., 2019; Sánchez-Bayo & Wyckhuys, 2019).

Finding agroecosystems with the right balance between agriculture and food production, with high levels of biodiversity and ecosystem services will be challenging. First, we still face limitations in the assessment of biodiversity and ecosystem services, in understanding the underlying mechanisms that generate many ecosystem services, and in capturing the relationship among ecosystems services themselves and with agricultural practices at different scales (Lavorel & Grigulis, 2012; Rodríguez-Ortega et al., 2014). These limitations relate to challenges with the metrics used, the methodologies deployed and the different spatial and temporal scales involved.

Second, that poses a challenge in determining proper management in agroecosystems. Ecosystem services (including food production) are usually delivered in bundles (Raudsepp-Herne et al., 2010) and at different scales, from soil to landscape level (Schulte et al., 2014). While synergies occur between ecosystem services, there are also trade-offs among them. The clearest trade-off is the negative relationship between agriculture, and the production of food as a provisioning ecosystem service, with many other ecosystem services, and with biodiversity (Foley et al., 2005; Kok et al., 2020b). However, trade-offs may also occur among several desired ecosystem services, as well as with biodiversity (Lavorel & Grigulis, 2012; Schulte et al., 2014).

Last, and third, the uncertainty described above and the presence of several actors in decision-making may hinder action. Actors involved in the design and implementation of strategies to enhance biodiversity and the provision of ecosystem services usually face differences in terms of definitions, values, and priorities (Kok et al., 2020b; Pascual et al., 2021). The design and implementation of effective strategies to foster biodiversity and ecosystems in agroecosystems will need to involve a range of actors, notably regional actors, and their plural views (Lescourret et al., 2015; Pascual et al., 2021), develop different models of governance (IPBES, 2019) and embrace uncertainty (Muscat et al., 2021b).

6.3 Farm management matters: examples of farming systems that sustain biodiversity conservation and provision of ecosystem services

We will here focus on pasture-based livestock farming systems in Europe as an example of traditional agroecosystems that have large potential to maintain biodiversity and deliver ecosystem services (Cooper et al., 2009; Rodríguez-Ortega et al., 2014). A literature review of these farming systems in Europe showed their relevant contribution to provisioning services (e.g., meat, milk and fiber production), supporting services (e.g., gene-pool protection, including biodiversity), regulating services (e.g., climate regulation, prevention of natural

TABLE 6.1 Relative importance of ecosystem services, expressed as percentage of total willingness to pay in € per person per year, delivered by pasture-based livestock farming in Mediterranean, Alpine, and Atlantic agroecosystems. (From: Bernués et al., 2019).

Agroecosystem	Provisioning	Regulating	Supporting	Cultural
Mediterranean	20.2	53.2	18.4	8.2
Alpine	2.9	49.6	25.3	22.0
Atlantic	27.6	26.9	22.4	23.1

hazards), and cultural services (e.g., the aesthetic value of the landscapes, Rodríguez-Ortega et al., 2014).

Nonetheless, the value of non-market functions, such as those derived from non-provisioning services (i.e., regulating, supporting and cultural services), depends deeply on societal perception. Therefore, it is expected that not all ecosystem services delivered by these livestock farming systems have the same relevance in different countries or regions. Previous studies on mountain agroecosystems in different regions of Europe (Mediterranean in Spain, Alpine in Italy, and Atlantic in Norway) corroborate this (Bernués et al., 2019). The relative socio-cultural and economic value of each ecosystem service linked to these mountain farming systems was obtained using individuals' stated behavior in hypothetical choice settings (Bernués et al., 2019). Specifically, using a survey-based choice experiment, where individuals were asked to choose between a series of combinations of attributes (ecosystem services) and levels (defined in biophysical terms). When individuals made their choice, they compromised between the levels of the attributes (hence, emerging trade-offs). Except for regulating services, the ecosystem services considered per category were the same across regions (i.e., production of quality products linked to the territory as provisioning services; the maintenance of the agricultural landscape as a proxy for cultural services; and biodiversity conservation as supporting services, Table 6.1). The importance of regulating ecosystem services was context-specific (i.e., wildfires prevention, water quality and soil fertility in the Mediterranean, Alpine, and Atlantic agroecosystems, respectively).

The relative importance of each ecosystem service delivered by pasture-based livestock farming systems varied across regions, highlighting important specificities of each area, for example, the social relevance of the prevention of wildfires in Spain, the maintenance of water quality in Italy, and the maintenance of soil fertility in Norway. Furthermore, previous studies indicated that the relative importance allocated to these different ecosystem services depended on the sociological background, farmers giving a high value to regulation and supporting services, and non-farmer citizens rating provision and cultural ecosystems higher (Bernués et al., 2016).

The link between agriculture and ecosystem services (and disservices) is mediated by farming systems defined by specific agricultural practices. However, the effects of agricultural practices usually depend on the socio-cultural and biophysical characteristics of the social-ecological system where farms are embedded. Previous research used expert knowledge to assess the effect of specific agricultural practices on ecosystems services in Mediterranean and Atlantic mountain agroecosystems (Bernués et al., 2022; Rodríguez-Ortega et al., 2018). Thirty-six agricultural practices were evaluated for the Mediterranean and Atlantic agroecosystems (26 practices common to both). The comparison between the mountain agroecosystems in the Mediterranean and Atlantic regions showed, as expected, that even the common agricultural practices do not have the same perceived effect on ecosystems services in both regions (Bernués et al., 2022). This suggests the need for regionalizing the research efforts and, consequently, agri-environmental policies to increase their efficiency and social and environmental benefits (Aguilar-Gómez et al., 2020; Scown et al., 2020).

However, some agricultural practices were relevant for ecosystem service delivery in both agroecosystems. Especially, grazing and silviculture practices (such as extending the grazing period, grazing in semi-natural habitats, grazing in remote and abandoned areas, adapting stocking rate to the carrying capacity, and moving flocks seasonally) stand out for their relevance in delivering a wide number of ecosystem services and enhancing biodiversity. This highlights the potential of grazing and silviculture practices to deliver bundles of ecosystem services, and hence, importance of rationally promoting these practices in agri-environmental policies (Rodríguez-Ortega et al., 2014). A recent review on the effect of both livestock and wild ungulate grazing in Mediterranean forest pastures on ecosystem services found that most studies focused on supporting and very few on cultural and regulatory services, and concluded that the positive or negative impacts (disservices) were dependent on stocking rates (Velamazán et al., 2020).

6.4 The righteous farmer pays the sinner's bill: we have a lot of work to do

The objectives of agricultural policies have changed over the years from programs oriented to increase agricultural productivity to more integrated multifunctional approaches aimed to enhance the quality of life in rural areas and protect and restore the environment, with special attention to biodiversity conservation and climate action. Despite this, worldwide, agricultural support policies are failing to address ongoing environmental degradation, biodiversity decline, climate action and societal demands for sustainability, moving us away from our 2030 Agenda and the Sustainable Development Goals (European Court of Auditors, 2020; FAO, UNDP & UNEP, 2021; Pe'er et al., 2019). Agroecosystems with large negative externalities are still being rewarded worldwide through direct and indirect public policies. By contrast, traditional agroecosystems, which are the backbone of many rural areas of high nature value, and which provide high levels of ecosystem services and public goods, are primarily neglected (Navarro & López-Bao, 2019; Scown et al., 2020). Therefore, the current approach of most national and international agricultural policies, as well as the financial sector (Ripoll-Bosch & Schoenmaker, 2022), seems to reinforce the trend of agricultural intensification, abandonment and disappearance of traditional agricultural systems, and simplification and homogenization of landscapes, which is detrimental to biodiversity conservation and the maintenance of ecosystem services.

An urgent reorientation of agricultural support policies is required, and for this, there must be coherence with the different local, national and international agendas and agreements, such as the Biodiversity 2030 and the Farm to Fork strategies. In this sense, previous studies have shown that such political strategies are not always coherent and aligned, particularly when it comes to implementation (Muscat et al., 2021b). There are growing calls and initiatives to further harmonize sustainability agendas, such as addressing climate change and biodiversity loss together (Pörtner et al., 2021) or the food and biodiversity loss crisis (Leclère et al., 2020). One-size-fits-all measures have been shown inefficient. Therefore, in this reorientation, it will be necessary to address context-specific social demands and climate and environmental priorities (Lampkin et al., 2020; Olander et al., 2017; Pe'er et al., 2020).

Mainstream policies above and consumer values that originate from the social system cannot reverse the loss of integrity of agroecosystem structure, processes and functions (Fig. 6.2). On the one hand, they are not compensating properly those farmers that play an important role as deliverers of public goods ("provider gets" principle), i.e., modulating the flow of regulating and cultural ecosystem services from the natural system to the social system. For instance, there is no yet full implementation of agri-environmental policies that pay for ecosystem services, or regulate markets of food products so they include a certification of the full range of services, provisioning and non-provisioning (e.g., quality labels of food products that contribute to the conservation of biodiversity). On the other hand, they do not account economically for environmental and public health costs ("polluter pays" principle) through, for instance, establishing taxes that would mean a significant increase of the current artificially low prices.

Under these circumstances, farmers seem to face two contrasting pathways for developing their business. They can vertically integrate with global use of resources and global markets, pursuing greater technical and economic efficiency (sustainable intensification pathway). This sustainable intensification of agriculture can be seen it as a "natural" transition from agro-industrial systems towards a greener niche. Supported mainly by technology (e.g., climate-smart agriculture, precision farming), it seeks to improve agricultural productivity while reducing environmental impacts (Conway, 1997; Kuyper & Struik, 2014). The main goal often mentioned is to feed our world, which will reach 10 billion people in

2050, respecting the planetary boundaries that provide a safe operating space for humanity (Gerten et al., 2020). Notwithstanding, some concerns arise as this alternative is mainly focused only on production, leaving aside the distribution and consumption parts of the agrifood system, which, as we already know, have also large negative impacts on the environment (IPCC, 2019) and constitute the main reasons for the persistence of hunger in the world (IAASTD, 2008). Alternatively, they can horizontally (area-wide) integrate with local resources and markets, pursuing lower use of off-farm inputs and production costs and greater added-value for products holding specific quality attributes (alternative pathway). Current policies and markets seem to stimulate the first pathway, although farmers' values, household characteristics and the local/regional socio-economic context also have a great influence on decision-making at the farm level (Muñoz-Ulecia et al., 2021). In addition, other major drivers related to climate change, general socio-economic trends, future diets, demographics, and the price of inputs (energy in particular) will shape decision making at the farm level, and the future evolution of agricultural production and the agrifood system at large (Fig. 6.2).

Novel policies trying to solve the agriculture-nature conflict can be organized around three approaches (Tanentzap et al., 2015): regulatory (e.g., limits on pesticide use or chemical fertilizers); community-based (e.g., promoting partnerships between different actors); and economic, for example, paying farmers for the full range of public goods they deliver. Payments for ecosystem services (PES) can be implemented instead of direct subsidies. Hence, famers could have incentives to deliver ecosystem services and support biodiversity, following, for example, alternative management principles like agroecology, agroforestry, circular agriculture, and organic agriculture. Muñoz-Ulecia et al. (2022) in a study in Spain and Italy found that most people, regardless of their attitudes towards the agrifood systems-environment debate, including the livestock environmental impact, the quality and marketing of food products, and the rural development, supports a higher delivery of ecosystem services. This finding is consistent with several studies showing a general societal willingness to improve the agroecosystems delivery of ecosystem services (even at the expense of paying higher taxes) (Bernués et al., 2014; Faccioni et al., 2019; Huber & Finger, 2020), and widespread strong environmental concerns (de Groot et al., 2011; Grendstad & Wollebaek, 1998; Thomson & Barton, 1994). However, as Muñoz-Ulecia et al. (2022) noted, the differing attitudinal dimensions underlying people preferences may result in disagreement and conflict on the specific policy measures to be implemented.

For the PES system to be effective, regulating and cultural ecosystem services, such as the ones identified in the previous section, must be incorporated into decision making. They cannot be readily translated into monetary values, so their socio-cultural value need to be considered. Any PES system should be based on existing scientific evidence about the effects of agricultural practices and land management regimes on the environment. However, the socio-cultural, economic, and biophysical contexts across different sites strongly influence the public perception and value of ecosystem services (e.g., the prevention of forest fires is key in Mediterranean countries but not in northern Atlantic areas, as shown previously). Therefore, policy design needs to be flexible and accommodate different stakeholder values and environmental targets.

Research has also shown that there is a significant underestimation of the socio-cultural and economic values of ecosystem services delivered by agroecosystems across Europe (Bernués et al., 2019), and a large welfare loss linked to further abandonment of these areas. By individualizing support at the farm or local level, monitoring objective indicators for ecosystem services, and targeting particular agricultural practices, the so-called "green" subsidies may become rewards for the delivery of ecosystem services and biodiversity to society.

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