CHAPTER SIX

Roadmap for transformative agriculture: From research through policy towards a liveable future in Europe

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Abstract

Agriculture needs to be fundamentally transformed to be able to live up to and achieve Sustainable Development Goals and thereby improve its contribution to human well-being, as its outputs recently crossed global and European planetary boundaries. Reducing the use of agrochemicals by 75–86%, restoring 2/3 of the land

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to biodiversity rich habitats and achieving net zero emissions are the key measures to return to the path within the boundaries. Some recent policy initiatives, such as the EU Green Deal and the Kunming–Montreal Global Biodiversity Framework, set targets for such transformations by 2030. However, if these are not fully applied, no more progress can be expected than from previous failed environmental policies. We identified knowledge gaps, imbalances and other challenges, and we propose a roadmap to transform agriculture: fill knowledge gaps with research that links yield and income with ecosystem services; improve diet and nutrition; improve water retention; develop farming for both biodiversity and carbon sequestration. We argue that traditional farming systems and their knowledge holders can provide key information for setting the baselines of transformative agriculture. As a second step, capacities for a well-functioning science–policy interface need to be strengthened, where diverse evidence is used and harmonised to achieve an overarching nature-positive policy framework. Finally, we stress that implementation should be coherent by 2030 and set the path for transformation so that by 2050, European agriculture can provide healthy food and fair livelihoods in a healthy environment.

1. Introduction

Planetary well-being is strongly linked to healthy, functioning ecosystems (Hernández-Blanco et al., 2022; IPBES, 2019). An important factor behind healthy ecosystems – including agroecosystems dominating the terrestrial part of the Globe – is their biodiversity, which supports resilience, for example, against diseases, pest infections, instability, invasion of exotic species, etc. (de la Riva et al., 2023; IPBES, 2019). The ongoing loss of biological diversity thus undermines the very foundation of the future of humanity (Díaz et al., 2015; WEF – Word Economic Forum, 2023).

Biodiversity decline has prompted radical but mostly non-binding policy responses at both European and global levels. Prominent examples are the European Commission's Green Deal and its Biodiversity Strategy in particular (European Commission, 2020a) and the Kunming–Montreal Global Biodiversity Framework (KMGBF – CBD/COP/15/L25, 2022) both targeting 30% protection of lands and seas by 2030 and restoration of degraded ecosystems, among other objectives. The need for such decisive initiatives was called upon after not a single of the 20 Aichi Biodiversity Targets adopted by the Parties to the Convention on Biological Diversity has been met (CBD, 2020), and, similarly, biodiversity and ecosystem services continued to decline in the EU member states despite the "greener" reformed Common Agricultural Policy (CAP) (Pe'er et al., 2014, 2022). Furthermore, such ambitious and vital initiatives are requested and highly supported by the scientific community, which calls for urgent and integrated actions to bend the curve of biodiversity loss (Leadley et al., 2022; Pe'er et al., 2023).

Intensive agriculture is the major driver behind land use change, the largest threat to wild nature, affecting all facets of biodiversity and ecosystem services (Green et al., 2005; IPBES, 2019; Vanbergen et al., 2020). Furthermore, it is a significant contributor to climate change due to greenhouse gas emissions (IPCC, 2023), a major risk factor for human health, contributing to 11 million premature deaths annually (DeClerck et al., 2023). Agriculture is directly affecting c. 40% of the land surface both at the global and EU level through land conversion and agricultural intensification when machinery, agrochemical use, etc. are involved (Eurostat, 2020). The use of agrochemicals resulted in the trespass of planetary boundaries and biogeochemical cycles multiple times (Brunori et al., 2020; Steffen et al., 2015). Land use change, N and P use overshot the European planetary boundary by 400%, 600% and 450%, respectively (European Environment Agency, 2020). As a contrast, there is strong evidence that multiple-use areas, including non-intensively farmed agricultural landscapes, can support high levels of biodiversity, similar to strictly protected areas (Elleason et al., 2021). Despite harbouring threatened species and providing further contributions to people, habitats associated with agriculture have the worst conservation status among ecosystems (Pe'er et al., 2014; Rigal et al., 2023).

In this paper:

- we shortly present the ecological state of European farming systems, addressing some of its drivers and the underlying processes,
- we identify major knowledge gaps to reach the biodiversity-related policy targets,
- we provide a roadmap for research and policy developments to transform the farming system, so as to be able to provide a liveable environment in Europe.

2. State of biodiversity on farmlands

There is robust and convincing evidence of the decline of farmland biodiversity at all spatial scales. In Europe, most regulating ecosystem services declined due to intensive agriculture, whereas the high-input production of food, feed and biomass-based fuels increased (IPBES, 2018); such changes are associated with a significant loss of farmland biodiversity.

Recent analysis on common farmland birds proves the dramatic decline of populations and suggests that fertiliser and pesticide use is the main reason behind the decline (Rigal et al., 2023; see also Tscharntke and Batáry, 2023). Similarly, in another pan-European study, Emmerson et al. (2016) showed the harmful effects of agricultural intensification on a range of taxonomic groups and ecosystem services in European agroecosystems.

The collapse of farmland biodiversity is very much combined with the loss of multifunctional low-intensity traditional agriculture and semi-natural landscape elements (like hedgerows, field margins), as these have been replaced by homogenised, nonresilient, input-dependent, production-oriented and higher-yielding farmlands (de le Riva et al., 2023; Vanbergen et al., 2020). As a result, 60–70% of soils in the EU are currently unhealthy, and costs associated with soil degradation are estimated at over €50 billion per year (European Commission, 2023), questioning the future of food security and sovereignty (Altieri et al., 2012). Furthermore, climate change is expected to amplify and accelerate the deteriorating effects of conventional farming (IPCC, 2023; IRP, 2019).

Traditional extensive practices (e.g. grazing, mowing, scattering of hayseeds, few and less invasive machines, rotation systems and manuring instead of agrochemicals) do in fact create small-scale disturbances resulting in a highly diverse matrix of semi-natural habitats that favour a wide range of species, many of which are strictly dependent on these human activities (Babai and Molnár, 2014; Paracchini et al., 2008; Sutcliffe et al., 2015). The policy-driven drastic increase in farm sizes, mechanisation of agriculture and large-scale application of pesticides and fertilisers, on the other hand, led to the transformation of these highly diverse cultural landscapes into large-scale intensive monocultures (Batáry et al., 2017; Clough et al., 2020; Lefebvre et al., 2012). The disintegration of the traditional landscape matrices triggers not only the gradual disappearance of their associated biodiversity but also the loss of knowledge providing their maintenance (Babai and Molnár, 2014; Palang et al., 2006).

3. Steps towards biodiversity-friendly policy environment

The degraded status of farmland biodiversity in Europe and the need to return to more natural conditions have been acknowledged at policy levels (e.g. the European Green Deal – addressed later). Taking this path, we can let nature do the job by helping to restore ecosystem functions, like pollination, which can promote agricultural production and support biodiversity recovery at the same time (IPBES, 2016). The application of ecological concepts and principles in agriculture has been urged to address the challenges posed by the multiple conflicts between modern, intensified, industrialised agriculture. This introduced e.g. 'agroecology', organic farming, wildlife-friendly farming as new directions of practice (Altieri et al., 2012; Bohan et al., 2022; DeClerck et al., 2023; Green et al., 2005; Wezel et al., 2009). All these directions have a common aim, i.e. to balance the need for modernisation and productivity increases without losing the multiple benefits of traditional agriculture. In line with this and recognising the overlap between the biodiversity hotspot semi-natural areas and certain traditional farming practices, the EU introduced an agri-environmental indicator, the High Nature Value Farmland (HNV) concept (European Environment Agency, 2010; Paracchini et al., 2008).

These approaches – together with others, like ecological intensification (Bommarco et al., 2013) or regenerative agriculture (EASAC – the European Academies' Science Advisory Council, 2022; Rhodes, 2017) – provide the proper conceptual framework for sustainable agriculture in the context of climate change, offering synergies between carbon capture and storage and the enhancement of biodiversity (DeClerck et al., 2023; Vanbergen et al., 2020). However, there is a need for both more detailed advice as well as evidence from the research community for effective policy development for the much-needed transition.

Indeed, the European scientific community has been pro-active in the recent past and did already provide clear and pertinent advice via the science–policy interface (SPI). Prominent examples are two reports by the European Academies' Science Advisory Council: one on the required support mechanisms of regenerative agriculture (EASAC – The European Academies' Science Advisory Council, 2022) and the other one on harmful effects of neonicotinoids (EASAC – The European Academies' Science Advisory Council, 2023).

After decades of inefficient and harmful policies (Kleijn et al., 2007; Pe'er et al., 2014, 2022), the European Commission changed course through its Biodiversity and Farm to Fork strategies, setting ambitious targets to transform agriculture (see details later). These strategies are operationalised in the Nature Restoration Law, which defines legally binding targets for the EU member states. The Kunming–Montreal Global Biodiversity Framework sets similarly radical – albeit non-binding – targets globally (CBD/COP/15/L25, 2022). Despite adopting such strategies based on solid scientific evidence, there is still a strong science–policy gap that hinders decision-making and action based on the best available knowledge. To set targets is one thing – to implement the same targets is quite another.

4. Solution: transformative change

Uncertainties regarding the baseline conditions lead to difficulties in formulating clear and effective targets. For example, by taking action to reverse farmland bird decline – at what level should it be restored? Or, by changing agriculture to use less agrochemical input – what should be the rate of decrease in the use of the respective chemicals? Although traditional knowledge can provide essential information and tactical recommendations for certain specific situations (e.g. how to increase structural and functional diversity of agricultural lands – Ogar et al., 2020; Santos et al., 2023), it cannot provide the quantitative measures required to support fundamental changes at large spatial scales. The planetary boundary approach (Rockström et al., 2009) – with its altogether nine boundary conditions – was used in two reports, which found similar results on how large these changes should be. The Resilience and Transformation report (Brunori et al., 2020) assessed significant steps needed in the five agriculture-related planetary boundaries: climate change, biosphere integrity, land system change, biogeochemical flows, and novel entities and chemical pollutions. Similar steps were defined by the European Environment Agency report (European Environment Agency, 2019) for land system change and biogeochemical flow values. The target values that ought to be reached for sustainable farming system no later than by 2050 are the following:

- Zero CO_2-equivalent net emissions by 2050
- Restore declining biodiversity and ecosystems; reach at least to the level anticipated at year 2000
- 2/3 of Europe's land needs ecosystem restoration
- Reduce phosphorous by 81%, and nitrogen by 86%
- Reduce pesticides by 75%

These ambitious target values reflect the aim for transformative change in European agriculture, substantially impacting the economy and society. Obviously, transformative change cannot be restricted to agriculture; there is also a need to change human behaviour, the valuation of nature, how farmers prioritise, etc. (Dixson-Declève et al., 1972). We need to overcome organisational inertia, political obstacles, vested interest, and the short-term thinking of various powerful lobby groups from within agriculture and industry and invert these into leverages for learning and adaptation (DeClerck et al., 2023; Dixson-Declève et al., 1972). To succeed, we need to emphasise the fundamental dependence of humans on nature, clarify the systemic dimension of the issues and causes, pressures, targets and actors, and capitalise on scientific expertise and local knowledge (Dupuis et al., 2023). There is already a significant move towards the greening of finance and biodiversity awareness in the public, but with great regional imbalances (Troumbis, 2021).

5. Obstacles to transformative change: knowledge gaps, imbalances, and other challenges

There are various sources of knowledge gaps and/or research priorities in policy and scientific literature. Below, we provide a list of the most relevant gaps for reaching a sustainable European farming system from IPBES sources. Both the Europe and Central Asia and the Global assessments provided a comprehensive list of knowledge gaps (IPBES, 2018, 2019). We reviewed the two lists and screened and modified the gaps to produce the following reduced list containing the most important ones for European agriculture.

1. Knowledge of how biodiversity contributes to ecosystem services and how species traits affect these patterns.
2. Understanding the impact of climate change in combination with context-specific drivers on biodiversity and ecosystem services, especially concerning tipping points and planetary boundaries.
3. Data on the comparative effectiveness of different models for reconciling bioenergy and biodiversity.
4. Lack of monitoring programmes, especially for fungi, non-vascular plants, invertebrates, and soil organisms. Monitoring should also address ecosystem functioning and species interactions. Such data may help understand time lags in drivers' effects on biological diversity and ecosystem services.

5. Exploration and conservation of genetic diversity of breeds of farmed plants and animals.
6. Mapping ecosystem conditions, developing restoration methods and monitoring their success.
7. Assessment of the impacts of environmentally harmful subsidies.
8. Syntheses of traditional and local knowledge and integration into national and international policy frameworks and initiatives to create synergies across knowledge systems.
9. Data on the impacts of war and conflicts on nature and nature's contributions to people.
10. A better understanding of the interaction between different policy instruments in existing policy mixes, not just the optimisation of single instruments.

The above list is our selection from IPBES, 2018, 2019. Thus, we acknowledge the existence of many further knowledge gaps and research priorities in agriculture (Pretty et al., 2011; Brown et al., 2016; Neve et al., 2018, etc.), arising from various specific approaches. However, an important gap emerges from human behaviour, like: (a) an awareness gap: people are not sufficiently aware of the depth of biodiversity degradation; (b) a motivation gap: people are not sufficiently aware of how biodiversity degradation affects their daily lives; (c) an action gap: awareness does not turn into motivation to act, often because action faces costly trade-offs (European Environment Agency, 2019; Troumbis, 2021).

A major cause of these knowledge, awareness and action gaps is the unbalanced representation of geographical regions and taxonomic groups in research. In Europe, the available expertise is highly biased towards the West (e.g. Báldi and Palotás, 2021). Yet, the level and stability of farmland biodiversity are known to increase towards the East and South, in relation to landscapes where fields are smaller and agriculture is less intensified (Clough et al., 2020; European Environment Agency, 2010; Palang et al., 2006; Pilotto et al., 2020). The gap in knowledge for non-popular and hard-to-identify taxa has been known for a long time (Clark and May, 2002; Hughes et al., 2021), also influencing policy targets, with substantially higher investment per species towards vertebrates vs. invertebrates and animals vs. plants (Adamo et al., 2022). A further difficulty lies in the level and accessibility of existing biodiversity knowledge, which is again biased towards the West, partly due to higher levels of internationally visible data and fewer non-English-language publications (Amano et al., 2023; Sutcliffe et al., 2015).

Defining baseline conditions is a major obstacle in conserving and restoring ecosystems (Westwood et al., 2014). Again, traditional knowledge and the oral histories of locals can provide information regarding the pre-impact state of ecosystems, and help address the deformed landscape valuation and lack of understanding of ecological processes (i.e. shifting baseline syndrome – Soga and Gaston, 2018), thus support setting baselines for restoration (Mustonen, 2013).

Given that many innovation systems are built upon old paradigms, research often does not provide adequate solutions to emerging environmental problems. Business and policy actors are locked into systems that impose on them a given behaviour, and the search for alternative pathways could be costly and risky.

6. Policies in – or should be in – support of transformative change

While the number of policy measures that aim to conserve farmland biodiversity is increasing, biodiversity continues to decrease, and there is no temporal improvement in sight, which questions the effectiveness of these measures (Batáry et al., 2015; Kleijn et al., 2007; Pe'er et al., 2014, 2022). Instead of making agriculture 'greener', the CAP has actually encouraged its specialisation, leading to further intensification and consolidation of small family farms and parcels, reducing the diversity of practices at the landscape scale and contributing to the accelerated erosion of farmland biodiversity (Batáry et al., 2015; European Commission, 2019; Kindvall et al., 2022; Lefebvre et al., 2012; Pe'er et al., 2014; Santos et al., 2023; Simoncini et al., 2019). These risks are particularly valid in Central and Eastern Europe, where landscape matrixes and traditional farming practices still maintain high biodiversity value areas (Fig. 1) and where agri-environmental regulations (e.g. mandatory date of mowing or lack of support for farmers working on less than 1 ha of land and parcels smaller than 0.3 ha, see text box) undermine the continuation of these practices, thus threatening endangered species and habitats (Babai et al., 2015; Bobiec et al., 2019; Kindvall et al., 2022; Molnár et al., 2023). These traditional practices are essential for maintaining the European biocultural landscape. There is a need for supportive rather than prohibitive policies that could make rural areas more attractive, with clear economic and social benefits to prevent alienation (Palang et al., 2006; Simoncini et al., 2019). Reflecting on these

Fig. 1 The matrix of differently managed parcels enables the maintenance of High Nature Value Farmland in Transylvania, Romania. *Photo by Kinga Öllerer*

drawbacks, in January 2023, the modernised CAP 2023–27 entered into force. It seeks targeted support for smaller farms and greater flexibility for EU countries to adapt measures to local conditions (Box 1).

Box 1 Mowing date regulations and their devastating effect on some species and habitats of conservation focus – experiences from the ground.

EU agri-environment schemes prescribe different mowing dates depending on the measure category and associated management prescriptions, which conflicts with the traditional mowing calendar, particularly with rotational mowing applied in mountain hay meadows. The data, mainly based on regular monitoring of birds, suggest that the zonal thematic prescriptions, compared to the applied horizontal thematic prescriptions, can ensure the maintenance and even enhancement of natural values. The prescribed earliest mowing dates are impractical, as hay cut later has lower quality, and are biologically harmful from a conservation point of view. For example, while

the breeding of the corncrake (*Crex crex*) can be ensured on wet meadows by delaying mowing (allowed after 1 August), it is impossible to maintain large populations of the blue butterfly (*Phengari*s spp.) with the same regulations, though the species can coexist. Prescribed mowing takes place at the peak of the swarming period for these endangered butterflies; therefore, no suitable food plants are available for egg-laying. Assuming adaptive conservation management, mowing at a maximum rate of 50% before 10 July and 40% after 31 August would be the optimal.
See more examples on the need for local fine-tuning of regulations: for mountain hay meadows (Babai and Molnár, 2014; Babai et al., 2015); wooded landscapes (Bobiec et al., 2019); species-rich fens (Kindvall et al., 2022); mountain vineyard landscapes (Santos et al. 2023).

In order to prevent the development of damaging initiatives in the future, the need for an integrative vision and comprehensive policies has been recognised, resulting in several important projects, now in progress, that urge systemic, socio-economic transformative change. The IPBES plenary, for example, initiated the undertaking of the "Thematic assessment of the underlying causes of biodiversity loss, and the determinants of transformative change and options for achieving the 2050 Vision for Biodiversity" within its 2019–2030 work programme. It objective is to describe the vision of a sustainable world – for nature and people and how transformative change can be achieved (see https://www.ipbes.net/transformative-change). Nevertheless, its recommendations will only have to be complied with on a voluntary basis. Similarly, the KMGBF targets (and the Paris climate targets) are ambitious, but neglecting them has no consequence for the governments. In order to achieve the goals set, these policies should be legally binding. To maintain human well-being, we have to transform our economy, society and related monetary and non-material values, including those related to agriculture.

One a positive note, the European Green Deal sets legally binding targets and deadlines for its member states in its proposed laws and regulations. The European Commission adopted a package of commitments and actions (the consecutive Biodiversity and Farm to Fork Strategies in particular, European Commission, 2020a,b) and has further proposals (e.g. the Soil Monitoring Law, European Commission, 2023) for sustainable use of natural resources to ensure a shift to a sustainable food system, promote farming with a neutral or positive environmental impact and reverse the loss of biodiversity. It aims to reach this by the reduction of pesticide use in agriculture and antibiotics in livestock by 50% and synthetic fertilisers by at least 20% by 2030 and bring back at least 10% of agricultural area under high diversity landscape features by 2030, amongst other objectives (more details and updates on https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (Schneider et al., 2023). Scientists have concluded that the success of the Farm to Fork Strategy lies in addressing the entire food system, from its production to consumption (EASAC – The European Academies' Science Advisory Council, 2022). Thus, sustainable and healthy food should be available for everyone, and food literacy has a major role (http2, 2023). Result-oriented approaches in agri-environment schemes aimed at changing farmers' attitude are more likely to initiate the socio-cultural changes needed for such systemic transformations (Burton and Schwarz, 2013; Fleury et al., 2015).

These commitments and plans are, however, questioned at the highest political and economic levels, which risks prolonging the period of biodiversity decline and delaying the bending of the curve of its loss, ultimately jeopardising the achievement of the desired goals (Leadley et al., 2022; Pe'er et al., 2023). One recent example of how political debates can hinder the advance of recovery is that of the EU's Nature Restoration Law, a crucially important element of the Green Deal (European Commission, 2022). The Nature Restoration Law was attacked by a multitude of lobby organisations using misinformation, resulting in the deletion of the proposal to restore agricultural ecosystems, and the introduction of multiple weakening derogations and exemptions despite strong scientific support of the initial text (Pe'er et al., 2023). Although the Nature Restoration Law was recognised as having great potential for ensuring effective implementation, there is still considerable uncertainty about its final composition (http1, 2023). Overall, there is an urgent need to strengthen evidence-based policymaking to achieve political will and commitment, overarching time-bound mandates and public and economic support for their implementation, as these should ultimately act for promoting and restoring farmland biodiversity. To reach this ultimate goal, we provide a roadmap for development.

7. Roadmap and leverage points

The alarming state of biodiversity and ecosystem services, the need for transformative change, and the policies supporting it all need evidence, long-term thinking with respect to the 2050 "harmony with nature" vision, and urgent and coordinated actions to be effective (IPBES, 2019). However, if policy and decision-makers do not use the available evidence and initiate sustained actions, they will have a responsibility to future generations to explain why. Here, we optimistically suppose that in the future evidence will be applied more effectively to shape sustainable development. Thus, we provide a roadmap for achieving a transformation of farming systems in Europe. The roadmap has three key elements building on improving political, economic and societal commitment: (i) fill the knowledge gaps with further relevant research, (ii) transfer the best available knowledge to the policy- and decision-maker area and provide improved policies with the necessary funding and binding transformation goals, and finally, (iii) increase coherence for effective implementation (Fig. 2).

7.1 Fill the knowledge gaps with further relevant research

We need multi- and transdisciplinary fundamental research that links ecosystem services with yield and other valuable measures for farmers (e.g. crop quality dependence on pollination, see Gazzea et al., 2023; Schneider et al., 2023). For that, farmland biodiversity research needs to go beyond species numbers and abundances to understand ecosystem functions and services

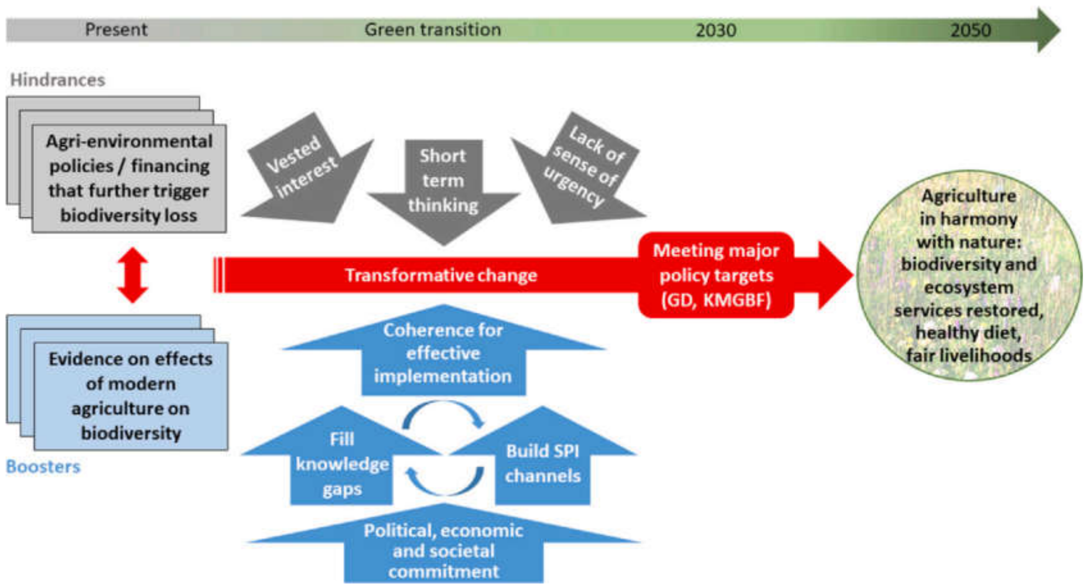

Fig. 2 Roadmap for transformative agriculture in Europe. Because of existing time lags, policy targets need to be met by 2030, which means agriculture will be on a transformative, sustainable and equitable path, and by 2050, the new system will be fully operational, and agriculture will be in harmony with nature, as a decisive step for human well-being. (GD = European Green Deal; KMGBF = Kunming–Montreal Global Biodiversity Framework; SPI = Science–Policy Interface).

(Bommarco et al., 2013; Emmerson et al., 2016; de la Riva et al., 2023; Rey Benayas and Bullock, 2012; Simoncini et al., 2019). Furthermore, we need to develop multifunctional agricultural systems that simultaneously meet production, environmental and societal targets based on cross-sectoral and participatory management (Hunter et al., 2017; Vanbergen et al., 2020).

A research programme is needed to improve diets and nutrition as people in general consume 2.5–3 times as much meat as recommended. Moreover, roughly one third of all food is wasted, consequently contributing to keeping agriculture intensive (Brunori et al., 2020; EASAC – The European Academies' Science Advisory Council, 2022). Two further important research areas to be developed relate to water and carbon. Studying the potential for water retention in the lowlands could help mitigate the effects of climate change to diversify agricultural cultivation and conserve species and ecosystems (Csákvári et al., 2021). Regenerative agriculture practices (e.g. intercropping, cover cropping, agroforestry, hedgerows) – and their ecological restoration component in particular – can potentially increase carbon capture and storage, and soil organic matter while also enhancing biodiversity and reducing – or eliminating – the need for fossil fuels (EASAC – The European Academies' Science Advisory Council, 2022). Here additional research is required with regard to the capacity for carbon storage – as well as permanence – in different types of soils.

The advance of agroecology (including ecological intensification) needs massive research evidence for efficient progress (Batáry et al., 2023). In addition, it requires addressing the underlying social issues to support education and awareness-raising to change the perceptions, values and behaviour of both farmers and consumers (Bohan et al., 2022; Wezel et al., 2009). This process could be supported by building on traditional farming practices and the underlying traditional knowledge. Traditional farming practices have been shown to maintain biodiversity and even create new species-rich semi-natural habitats (Babai and Molnár, 2014; Bugalho et al., 2011). Building on traditional knowledge and knowledge-holders could help develop tradition-based innovations to adapt current single-commodity-oriented intensive practices to sustainable multifunctional use systems, restore degraded habitats, and also bridge the existing knowledge gap on species and population distributions (Babai and Molnár, 2014; Biró et al., 2019; Csákvári et al., 2021; Jardine, 2019; Ogar et al., 2020).

The EU has probably the largest research-funding instrument on Earth, the Horizon Europe, which addresses some of these knowledge gaps but is not a game changer yet. Some developments, e.g. in the European

Biodiversity Partnership, are promising in addressing hot biodiversity issues like harmonising monitoring across Europe or promoting nature-based solutions (see https://www.biodiversa.eu/).

7.2 Building capacity for science–policy interface (SPI)

Research policies can have a strong role in filling these gaps. However, transformative change requires a transformative research policy based on (a) clear directions; (b) experiments in real life; (c) strong interdisciplinarity; (d) focus on impact; (e) social engagement. Research policies can (a) challenge old paradigms, which are mobilised to support resistance and delay new paradigms; (b) contribute to frame biodiversity degradation as a policy problem, addressing knowledge gaps and conflicts of values and interests in ways that create consensus through better knowledge; (c) provide win–win solutions that can help to overcome resistance of those who feel damaged.

Knowledge, science–policy interfaces and integrated actions are key to achieving transformative change (Duncan et al., 2022; Leadley et al., 2022). There are a number of issues where the science–policy interface has to improve in order to provide an effective communication channel. An effective SPI should harmonise policies with all research evidence, preventing sectorial policies from ignoring nature's contributions to people. SPI should also be channelled into the subsidy systems encouraging traditional local practices that benefit biodiversity (Babai et al., 2015; Bobiec et al., 2019; Kindvall et al., 2022; Santos et al., 2023; see also the text box). This can be achieved by effectively involving local communities and knowledge holders by respecting the commitments made in the recently adopted policy measures, including the European Green Deal and the KMGBF.

Research harmonisation, synthesis, and presentation of results to policymakers is a key function of the SPI. IPBES is providing a good example, already the first-ever assessment on pollinators (IPBES, 2016) has affected the European policy and research funding. The harmonisation and development of European monitoring programs can provide solid evidence on temporal trends (Moersberger et al., 2022). The Pan-European Common Bird Monitoring Scheme is running for many years already (https://pecbms.info/; Rigal et al., 2023), the pilot program of the EU Pollinator Monitoring Scheme (EUPOMS) is running these years (2021–23, https://wikis.ec.europa.eu/display/EUPKH/SPRING+project), whereas many others need to be integrated across Europe.

There is a great need for useful information, including increasing awareness, improving education, and supporting the digitalisation of agriculture (WEF – Word Economic Forum, 2023). An important role of SPI would be synthesising knowledge on various aspects of modernisation, like digitisation, the use of AI and other (bio)technological innovations in agriculture. Modernisation can be a game changer if applied under the cautionary principle, as there is much less knowledge and experience on how these influence ecosystem functioning and human health (Garske et al., 2021). As a default, mainstreaming biodiversity should stand at the basis of agricultural policies, investment priorities (e.g. modernisation) and actions (DeClerck et al., 2023).

To make research evidence effectively cross the SPI, we propose to involve policy-makers and legislators early in the scientific process and create platforms for discussion to identify issues that need a strengthened scientific background as well as further elaboration of policy options. One way is to invite them to be "ambassadors" of a certain topic to take lead roles at their respective policy environment. Another way would be to invite legislators to actively participate in scientific advisory committees and bodies that address the specific policy challenge. Such initiatives are the EU Commission's Knowledge4Policy (K4P) platform for evidence-based policymaking (see https://knowledge4policy.ec.europa.eu) and the Global Legislators Organisation – GLOBE, now supporting the implementation of the Rio Conventions (climate change, biodiversity, desertification – see https://globelegislators.org/). Another body to liaise with could be the Inter-Parliamentary Union (IPU).

7.3 Coherence for effective implementation

Implementation gaps emerge when knowledge gaps and/or the existence of conflicting policies create room for ambiguity, inaction and/or regressive forces. Hence, there is a need to identify interactions between different policies that either compromise or reinforce the achievement of the proposed targets. Conflicts between policy objectives and outcomes are caused by their sectorial "silos" approach as well as segregated funding. Consequently, many policies are enabling and fostering environmentally harmful investments and/or support incentives with negative impacts (see text box and the encompassing section). The problem is in the basics: policies regularly build on the narrow evidence they get or subjectively select, ignoring wider, long-term and often indirect impacts. Building on a coordinated approach and fostering synergies across scales, we need to stress incentives for farmers and the agricultural industry as a whole to do the right thing and refrain from subsidies that harm biodiversity – now equal to 2% of global GDP (Koplow and Steenblik, 2022) – and reorientate them to deliver a nature-positive economy (CBD/COP/15/L25, 2022; IPBES, 2019).

Therefore, farmers need better rewards for the environmental public goods and services they deliver to support the continuation of their activities and overcome alienation (Palang et al., 2006; Simoncini et al., 2019). On average, adoption of a practice increases by 16% for every 10% increase in farmers' perception of the economic benefits of that practice (WEF – Word Economic Forum, 2023). Unsupportive, detrimental top-down policies forcing traditional farmers into market competitions and causing the disrespect and abandonment of ecologically and culturally important land-use patterns and practices should be reconsidered from the perspective of the contribution of these knowledge holders to food sovereignty and agrobiodiversity (Altieri et al., 2012; Bobiec et al., 2019; Molnár et al., 2023). Similarly, there is a wide range of important issues where European agriculture has a severe global impact, including displacement of agriculture to developing countries, especially the Global South; import of palm oil, tropical fruits and timber and luxury products, such as cocoa or coffee, which trigger the loss of tropical forests (FAO, 2018, 2020; Koplow and Steenblik, 2022). Only initiatives to prevent and compensate/restore such impacts should receive public funding, with clear targets and performance indicators. Various elements of the Green Deal (e.g. proposed regulation for deforestation-free products) stress such changes in both investor and consumer behaviour for equitable and environmentally sustainable agriculture in Europe and beyond. All boosters and hindrances should be addressed simultaneously to embed biodiversity targets across the economic, social and policy dimensions of agriculture to empower transformative change (Fig. 2).

Consequently, we call for coherence that brings together the wide range of evidence on the impacts of conventional agriculture with policies and investments that are either supportive or potentially harmful to nature's contributions to people in order to develop, strengthen and implement an overarching harmonised, nature-positive policy framework.

8. Vision by 2050

The success and long-term impact of the transition towards transformative agriculture was the result of the collective commitment, collaborative efforts and actions of all stakeholders. The key policy targets set for 2030 (e.g. GD, KMGBF) delivered the changes needed to halt the erosion of the prospects for human well-being, as they were implemented urgently and in an integrated manner (Leadley et al., 2022). Indeed, a transformation of our value systems, behaviours, and above all – in our relationship to nature – made us worthy stewards of 'our common home' (Pope Francis, 2015).

As a first step, coherence between the knowledge on farmland biodiversity and policies was reached by 2030. Enhanced knowledge was the mechanism that helped improve the clear definition of policy challenges and create the consensus leading towards transformative change. By 2050, the course had been changed for European farmlands; the "business as usual" is new; its core had been transformed to "living in harmony with nature", within the planetary boundaries in good health. Biodiversity, ecosystem services and more broadly, nature's contribution to people had been restored. Food production is secured and provides a healthy diet. Food waste had been minimised. Negative effects on other countries – especially low-income countries – had been eliminated. Agriculture is in harmony with nature and we all benefit from a liveable Europe.

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