Supplementary information

A. Megatrend selection procedure

Longlist of trends constructed using the STEEP framework

Trend	Social	Technological	Economic	Environmental	Political
Demographic changes	X		X		
Urbanization	X		X		
Climate change impacts				X	
Climate change mitigation	X	X	X	X	X
Dietary changes			X		X
biotechnology innovation		X			
Agricultural industrialization		X	X		
Automation and mechanization		X	X		
Digitalization		X			
Inequality			X		X
Migration	X				X
Globalization			X		X
Shifting societal values and lifestyles	X			X	X
Natural resource scarcity			X		
Changing agri-food value chains			X		X
Financialization of agriculture					
Renewable energy developments		X	X		
Consumerism	X		X		
Global food security			X		
Global rush for land			X		X

B. Mapping procedures for environmental action space

Excess nutrients

For excess nutrients, the Farm2Fork strategy aspires to cut this by 50% by 2030. We use results from a coupled biogeochemistry (DNDC) and agricultural economic (CARPI) model (unpublished follow-up work similar to (Leip et al., 2008). These results are valid for 2018 and show the soil surface surplus of nitrogen based on the total nitrogen input and the crop or vegetation nitrogen retention. While no baseline is specifically mentioned in the Farm2Fork goal, we calculated an aspirational 2030 per-hectare target by summing the current excess nitrogen within the EU and dividing it by two. When this budget is evenly distributed across all current EU used agricultural land, a target of 45.7 kg $ha^{-1}yr^{-1}$ is derived. In other words, if every hectare produces only 45.7 kg of excess nitrogen annually, the 2030 target of -50% would be reached. This analysis does not take non-nitrogen nutrients into account. The resulting map shows, for each CAPRI farm soil unit, the level of exceedance compared to the target. The accompanying graph shows the percentage agricultural area exceeding the target by country.

Pesticide use

A similar aspirational target set out in the Farm2Fork strategy is to reduce the use and risk of pesticides by 50% by 2030. We engage with the use target, and use the PEST-CHEMGRIDS database (Maggi et al., 2019) to establish current pesticide use as well as a formal per-hectare target. Similar to the nutrient approach described above, we calculate a 2030 budget meeting the 50% reduction target by dividing the current total volume of pesticide use across all 20 active ingredients and all 20 crop groups in the PEST-CHEMGRIDS database in the EU by 2. We use the more conservative low estimates in this database. Distributing the thus acquired 2030 budget volume evenly across all used agricultural land in the EU yields a target of 1.4 kg $ha^{-1}yr^{-1}$. The map shows, for each PEST-CHEMGRIDS grid cell (5 arcmin cell size), the level of exceedance compared to the target. The accompanying graph shows the percentage agricultural area exceeding the target by country (taking into account within-cell shares of agricultural area).

Antibiotic use

The Farm2Fork strategy aims to reduce antibiotics use in livestock by 50% by 2030. However, we measure performance compared to a more widely recognized target of 50mg of antibiotics per population-corrected unit (Van Boeckel et al., 2017). A population-corrected unit corresponds to a kilogram of animal product. Current (2015) antibiotics use is mapped at the national scale, using data from the European Medicines Agency collated by Our World In Data (2021).

Emission intensity, share, and progress

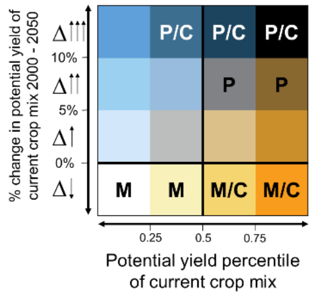
Emission intensity is measured as the total 2016 CO_2-equivalent emissions attributed to agriculture divided by used agricultural area (data: EUROSTAT (2021), gap-filled for Norway and Switzerland using numbers collated by Our World in Data (Ritchie et al., 2021).

The share of agriculture in total emissions was obtained by dividing the country's agricultural emissions by the total non-tradeable emissions. This denominator constitutes the Effort Sharing emissions, which are more relevant than total emissions because agricultural emissions cannot be traded in emissions trading schemes. Only binding targets set out in the Effort Sharing regulation therefore have bearing on agriculture.

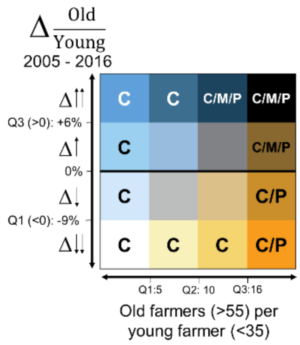
We measure to what extent recent emission reduction efforts in the Effort Sharing emissions are on- or off-track to meet binding 2030 targets by calculating the difference between the required annual emission cuts for each individual country to meet its 2030 target and the actually attained speed of emission reduction between 2005 and 2018 (data: European Environment Agency (2019b), gap-filled with Our World in Data (Ritchie et al., 2021)). We assume that large differences in attained versus required reduction speed imply that current strategies are insufficient and a contribution by agriculture is more likely to be demanded. Effort-sharing targets for Norway and Switzerland were derived from national policy documents (Federal Council, 2021; Norwegian Ministry of Climate and Environment, 2019).

C. Horizon scanning

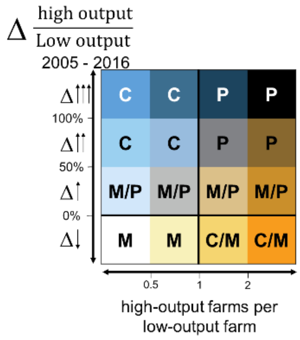
1. Climate change

	Mechanisms	References	Thresholds
Potential yield trends	**Negative → marginalization** Where climate change reduces biophysical suitability for the currently grown crop mix, in already suboptimal areas	9, 10, 11, 12, 24, 27, 30, 38	 M: Marginalization C: Systemic Change P: Persistence
	Negative → systemic change Where climate change reduces biophysical suitability for the currently grown crop mix and significant adaptation is needed. Farmers may change the crop mix, apply climate-smart solutions, build indoor or irrigation infrastructure, and improve their management strategies.	12, 20, 26, 27, 38	
	Positive → Persistence Where climate change increases biophysical suitability for the currently grown crops, the current system can become more competitive, reinforcing system resilience and removing incentives to change	11, 12, 13, 16, 17, 23, 25, 29, 30	
	Strongly positive → systemic change Where climate change makes the current system more competitive, this can enable investments and intensification	16, 38	
Drought risk trends	**Positive → marginalization** Where drought hazard increases and there is limited scope for adaptation	9, 11, 12	>0.7 increase in drought events/decade in 2041-2070 compared to 1981-2010 AND >50% likelihood of impact

2. Demographic changes

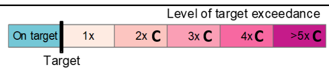
Farmer demography	**Very young; or getting younger → systemic change** Young farmers are more likely to make large changes in farm management	23, 28, 39, 40	 M: Marginalization C: Systemic Change P: Persistence
	Very old; or getting older → systemic change An ageing farmer population and limited succession can result in farm consolidation, scale enlargement, polarization, and automation	23, 40	
	Old; or very old and getting older → persistence Older farmers are less likely to make large changes in farm management	40	
	Very old and getting older → marginalization	41	
	Getting older → (sign of) marginalization An ageing farmer population with limited succession have a tendency to decrease management intensity or gradually abandon farming altogether. Ageing is also a sign of marginalization	8, 9, 23	
Trends in working-age population	**Decreasing → marginalization** Low labor availability can make farm system unviable and is a driver of land abandonment	7, 11, 28, 29	Annual working-age population change <1%

3. Productivism and post-productivism shifts

Economic farm size trends	High-EFS dominated regions with increasing EFS ratio trends → sign of persistence **The current system, characterized by productivism, continues**		 M: Marginalization C: Systemic Change P: Persistence
	Low-EFS dominated regions with slowly increasing EFS ratio trends → sign of persistence Gradual, incremental changes		
	Low-EFS dominated regions with rapidly increasing EFS ratio trends → sign of systemic change A reorientation towards productivism	1, 3, 5, 28, 30	
	High-EFS dominated regions with decreasing EFS ratio trends → sign of systemic change A reorientation from productivism to multifunctionality (very few cases)	30	
	Decreasing EFS ratio trends → sign of marginalization	33	
Emergence of very large livestock holdings	**Agglomeration of very large livestock holdings → sign of systemic change**	34, 35	Amount of livestock holdings with more than 500 livestock units > 170 (third quartile)

Emergence of organic agriculture	**High share of farmland managed organically → sign of systemic change**	1, 2, 3, 29	% of used agricultural area farmed organically > 9% (third quartile)

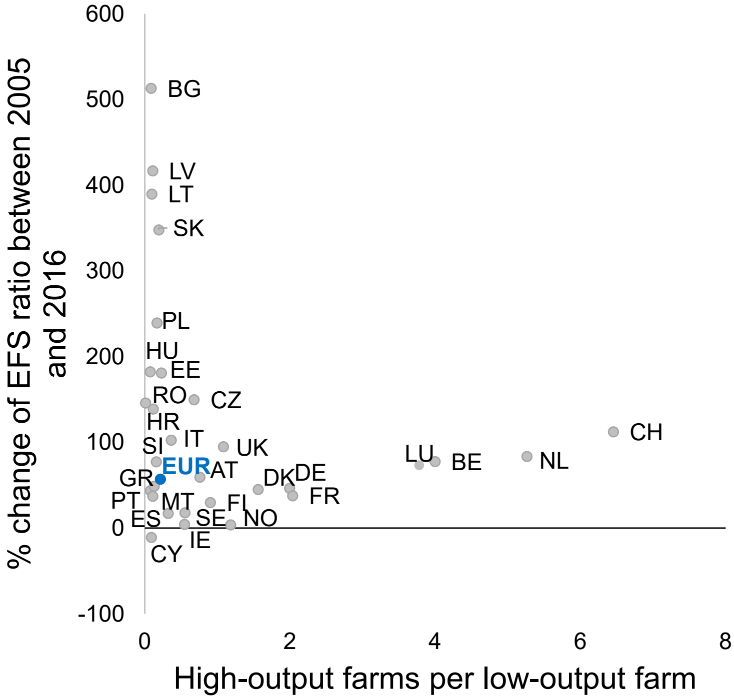
4. Environmental action space

Tightening of excess nutrient generation, pesticide use, and antibiotic use	**High levels of exceedance relative to proposed target → systemic change** Regions strongly exceeding announced targets are less able to meet targets using minor changes only and may instead need to drastically redesign their farm system	36, 37	 **C: Systemic change** Excess nitrogen > 91.4 kg $ha^{-1}yr^{-1}$ Pesticide use > 2.8 kg $ha^{-1}yr^{-1}$ Antibiotic sales > 100mg/PCU (Double exceedance of target)
Greenhouse gas emission policies	**Countries with high pressure on agriculture to contribute to reduction progress → systemic change** Regions in countries where the agricultural sector is characterized by a combination of high GHG intensity, a large contribution in total non-tradeable emissions, and insufficiently fast emission reduction progress are likely to require farm system redesign to meet their targets.	37	GHG reduction pressure score > 1.2 (third quartile)

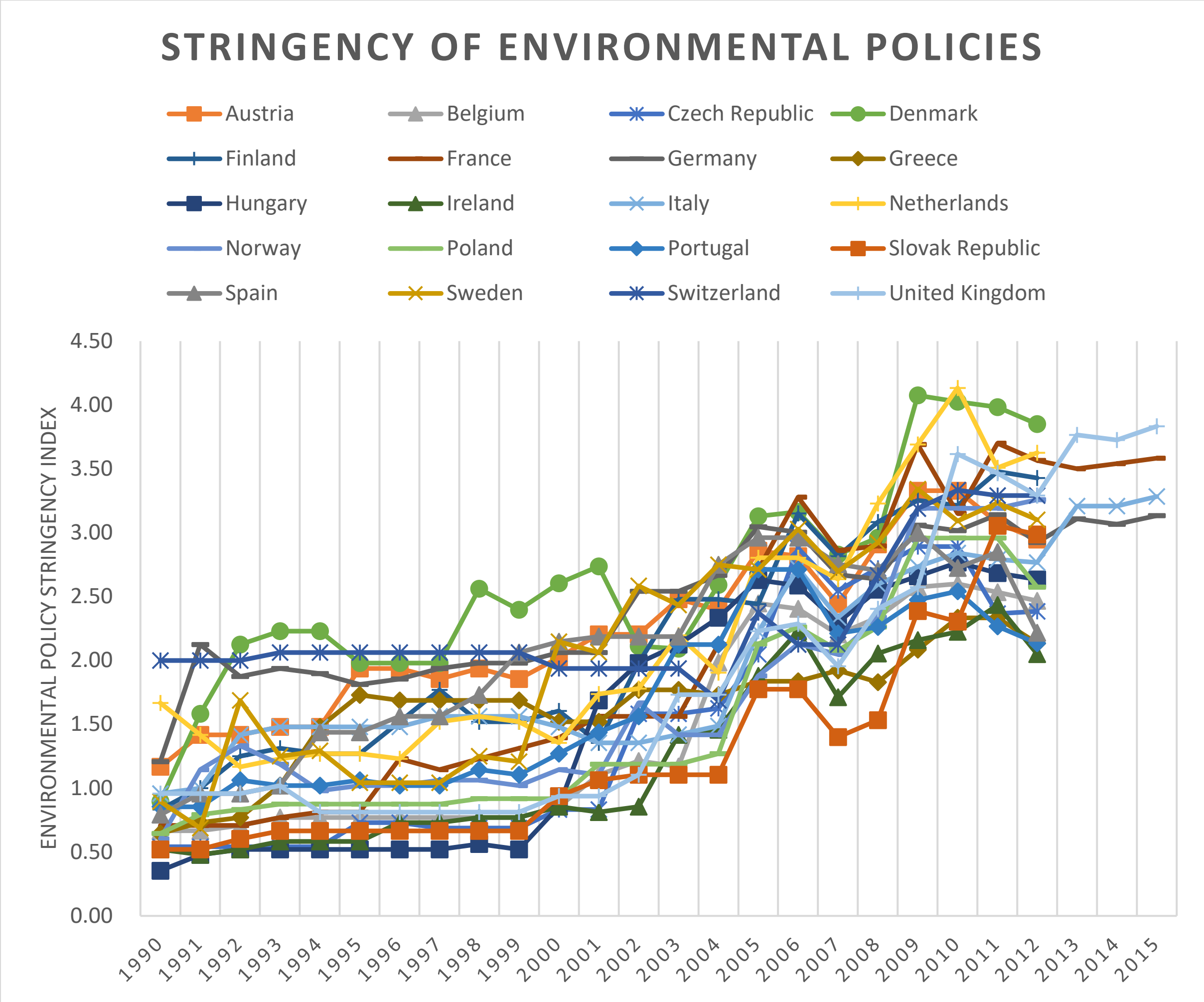
References in tables above:

1. (Robinson, 2018)
2. (Seufert and Ramankutty, 2017)
3. (Guiomar et al., 2018)
4. (Kienast et al., 2019)
5. (van Vliet et al., 2015)
6. (Dunnett et al., 2020)
7. (Lasanta et al., 2016)
8. (Benayas et al., 2007)
9. (Terres et al., 2015)
10. (Kosmas et al., 2015)
11. (Kuemmerle et al., 2016)
12. (Holman et al., 2017)
13. (van der Sluis et al., 2016)
14. (Adeh et al., 2019)
15. (Wens et al., 2019)
16. (Iglesias et al., 2012)
17. (Wiréhn, 2018)
18. (Aguilera et al., 2020)
19. (Lagacherie et al., 2018)
20. (Stringer et al., 2020)
21. (van Grinsven et al., 2019)
22. (Rojas-Downing et al., 2017)
23. (Plieninger et al., 2016)
24. (Levers et al., 2018b)
25. (King et al., 2018)
26. (Donatelli et al., 2015)
27. (Leclère et al., 2014)
28. (van Vliet et al., 2015)
29. (Levers et al., 2018a)
30. (Stürck et al., 2018)
31. (Zimmerer et al., 2020)
32. (Kasimis, 2009)
33. (Leal Filho et al., 2017)
34. (Breeman et al., 2013)
35. (de Bakker et al., 2012)
36. (Stokstad, 2019)
37. (van der Ploeg, 2020)
38. (Bindi and Olesen, 2011)
39. (Scherer et al., 2018)
40. (Zagata and Sutherland, 2015)
41. (Eistrup et al., 2019)

D. Economic farm size: additional visualization



E. Environmental policy stringency through time



Environmntal policy stringency index, as assessed by (OECD, 2016). The index is measures the environmental stringency, with scores ranging between 0 (not stringent) and 6 (highest degree of stringency).

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