The geography of megatrends affecting European agriculture

Debonne, Niels; Bürgi, Matthias; Diogo, Vasco; Helfenstein, Julian; Herzog, Felix; Levers, Christian; Mohr, Franziska; Swart, Rebecca; Verburg, Peter

published in
Global Environmental Change
2022

DOI (link to publisher)
10.1016/j.gloenvcha.2022.102551

document version
Publisher's PDF, also known as Version of record

citation for published version (APA)
Debonne, N., Bürgi, M., Diogo, V., Helfenstein, J., Herzog, F., Levers, C., Mohr, F., Swart, R., & Verburg, P. (2022). The geography of megatrends affecting European agriculture. *Global Environmental Change*, *75*, 1-14. [102551]. https://doi.org/10.1016/j.gloenvcha.2022.102551

Global Environmental Change 75 (2022) 102551

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The geography of megatrends affecting European agriculture

Niels Debonne[a,b,*], Matthias Bürgi[b,d], Vasco Diogo[b], Julian Helfenstein[c], Felix Herzog[c], Christian Levers[a], Franziska Mohr[b,d], Rebecca Swart[a], Peter Verburg[a,b]

[a] *Environmental Geography Group, IVM Institute for Environmental Studies, VU University Amsterdam, the Netherlands*
[b] *Land Change Science Research Unit, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland*
[c] *Agroscope, Zürich, Switzerland*
[d] *Land Systems and Sustainable Land Management, Institute of Geography, University of Bern, Bern, Switzerland*

ARTICLE INFO

Keywords:
Foresight
Sustainability
Socio-environmental system
Sustainability transformation
Europe
Horizon-scanning

ABSTRACT

A range of intensifying pressures is making the future of European agriculture dynamic and contested. Insights into these pressures are needed to inform debates about the future of the sector. In this study, we use a foresight approach to identify, quantify and map megatrends. Megatrends are long-term driving forces which are observable today and will likely have transformational potential in the future. By mapping these megatrends at the regional scale, we establish a geography of megatrends and detect where they coincide. Four megatrends significant for the future of European agriculture at the regional scale are assessed: Climate change, demographic change, (post-) productivism shifts, and increasingly stringent environmental regulations. The direction and intensity of these megatrends differs between regions, which drives regions into different systemic lock-ins or dynamics. In most regions, megatrends converge to destabilize the current system, forewarning impending systemic changes. While the specific megatrends contributing to this instability differ regionally, this result highlights that many regions are on a dynamic rather than stable trajectory, and the governance challenge is to steer these dynamics towards a desirable future. However, some regions are found to be highly persistent, indicating that megatrends reinforce business as usual, and change needs to be triggered through purposeful governance. In a minority of regions megatrends may drive marginalization as the current system becomes increasingly unviable. We argue that research and policies concerning agricultural sustainability transitions should be cognizant of the regional diversity of European megatrends and the pressures they create.

1. Introduction

European agriculture is faced with a multitude of interacting pressures and conflicting priorities. The future of agriculture in Europe is therefore both uncertain and contested. Major emerging pressures, such as climate change, demographic trends, technological innovation, or societal shifts, are believed to potentially lead to transformational changes in the coming decades. At the same time, in order to address challenges of climate change, environmental degradation, or food security, European agriculture is also required to undergo transformational changes (Fuchs et al., 2020; Leclère et al., 2014; Lee et al., 2019). There is a need for horizon-scanning in order to steer European agriculture to a desired future with transformations that are deliberately prioritized and away from unwanted transformations or undesirable lock-ins.

Studies aiming to envision the future of European agriculture and land systems more generally commonly assess drivers of change to determine the causes for dynamics observed in the past. The historical insights from these studies are then leveraged to explore the future using scenarios (Mitter et al., 2020), and integrated assessment models (Holman et al., 2017; Stürck et al., 2018). These studies typically engage only with relatively incremental processes of change (Filatova et al., 2016). In a context where change is both expected and required to be transformational, the applicability of these insights may be increasingly limited. Recent framings of agricultural change therefore use a human-environment systems framing and discuss change processes in terms of system resilience and transformations (Fazey et al., 2018; Müller et al., 2014).

(Agricultural) land systems are framed as socio-ecological systems having a level of resilience owing to negative systemic feedbacks that abate pressures of change. Any changes that do occur are typically incremental and predictable, and they do not fundamentally alter the

---

* Corresponding author at: De Boelelaan 1087, 1081 HV Amsterdam, the Netherlands.
E-mail address: n.debonne@vu.nl (N. Debonne).

https://doi.org/10.1016/j.gloenvcha.2022.102551
Received 1 September 2021; Received in revised form 14 March 2022; Accepted 3 June 2022

existing systemic properties or dynamics. However, when a sudden shock or a long-term accumulation of pressure undermines reigning negative feedbacks, change pressures overcome system resilience and a system transformation becomes more likely. In other words, transformative change is the result of a pressure built-up or shock.

While there is no definitive distinction between an incremental change and a transformation, Vermeulen et al. (2018) tentatively define transformation in agricultural systems as a redistribution of at least a third of the primary factors of production (land, labor, capital) in a relatively short time (<25 years). Filatova et al. (2016) define this more broadly as a fundamental shift in systemic functioning and traits. For example, in a socio-ecological systems framing, agricultural land abandonment is a transformation where the original agricultural land system's resilience is undermined by shocks (e.g. the end of communism or the entry into the Common Agricultural Policy) or long-term pressures (e.g. gradually worsening soil quality) (Lasanta et al., 2016). Other agricultural transformations include rapid greenhouse proliferation driven by co-occurring dietary changes, market integration, and climate change (e.g. in Southern Spain, Castro et al., 2019), or shifts towards labor-intensive agriculture driven by the availability of migrant labor (Zimmerer et al., 2020).

Transformations are the consequence of or response to shocks and long-term pressure buildup. Facing such pressures, responses can range between inaction, coping, incremental change, and transformational change (Fedele et al., 2019). It is often difficult or impossible to know at what level of pressure a transformation becomes likely, the gravity of systemic shocks required, or the timing of such shocks (Müller et al., 2014). Still, framing agricultural change through the lens of systemic transformations is useful both to foresee and prepare for upcoming transformations (Bauch et al., 2016) and to identify and break out of undesirable locked-in states (Oliver et al., 2018). A key challenge here is the identification of pressures that could potentially lead to transformational change or, conversely, lock-ins.

Here, we deploy the tools of the field of foresight studies to allow for ex-ante assessments of system transformations and resilience. Foresight (also known as futures studies) concerns itself with identifying possible, plausible, and desired futures by identifying and plotting megatrends. Megatrends are long-term driving forces that are observable now and likely have transformational potential in the future (OECD, 2019). This implies that megatrends are a specific subset of the more general "drivers", distinguished by their long-term nature and non-specific outcome specification. Traditional scenario studies typically build scenarios using pressures for which causality and likely impacts are established, but their future trends are uncertain (e.g. greenhouse gas emission scenarios). Instead, futures studies takes stock of trends for which the importance and future direction is relatively certain, although the specific impacts are not always clear or deterministic. For example, while it is uncertain what the specific impacts of an ageing society on European agricultural systems will be, it is known to be a trend that is pressuring rural areas, who have multiple ways to engage with and adapt to it (Zagata and Sutherland, 2015).

While foresight is commonly applied in strategic corporate settings, it is increasingly also being used to study socio-ecological systems. Kienast et al. (2019) explore megatrends that pressure ecosystem service provision in Europe. Oldekop et al. (2020) take stock of megatrends affecting forest-based livelihoods. Dynamics of a single watershed or community can also be studied using a megatrends approach (e.g. Carpenter et al., 2015).

Existing foresight on European agriculture has been deployed at the continental scale, without regional differentiation (Bisoffi, 2019; Bock et al., 2020). However, while megatrends typically manifest themselves at large scales, their intensity and implications can have a highly regionalized diversity. For example, climate change impacts are projected to differ dramatically between crops and regions (Ewert et al., 2015), and the changing role of value chains is affecting highly industrialized agricultural regions differently compared to regions dominated by smaller-scale producers. Given that agricultural policy is ultimately implemented mostly at the regional level, regionalized foresight can be an important tool, but an assessment of how megatrends affect European agriculture at the regional level is currently lacking.

Our aim is to go beyond existing futures studies on European agriculture by spatializing the megatrends approach in order to generate foresight at the regional level. We select those megatrends which have a distinct spatial manifestation and analyze their spatial distribution across Europe. We question where specific sets of pressures are converging spatially. In these places of convergence, megatrends may undermine current regional agricultural systems (moving regions towards transformations) or reinforce them (generating desired or undesired lock-ins). We deploy a megatrends approach which focusses only on those megatrends for which either the intensity and direction of the trend, or the sensitivity to the trend, vary by region.

In a context where the burden of future agricultural challenges is likely to fall on Europe's regions, a regionalized megatrends can serve to inform in which regions a convergence of megatrends is contributing to either persistence (where megatrends reinforce and lock-in the current system), systemic change, or marginalization (a specific systemic change where megatrends severely undermine systemic functioning, leading to unviability). In persistent regions, deliberate and purposeful governance is needed to compel sustainable transitions. Meanwhile, in regions where megatrends contribute to undermine the current system, systemic change is likely to occur and the governance challenge is to steer changes into desirable directions.

2. Methods

The most commonly used methodology in futures studies is a systematic megatrend analysis (IIASA, 2018; OECD, 2019). This analysis starts with the selection of megatrends relevant to the future dynamics of a well-delineated system. The past and likely future course of these megatrends is then explored by analyzing data on trends and dynamics of relevance to the megatrend. Lastly, in a horizon-scanning step, specific megatrend manifestations are linked with plausible implications. These steps are described below.

2.1. Selection of megatrends

To select the megatrends discussed in this study, we used a combination of foresight trend selection frameworks, existing foresight documents, study-specific selection criteria and iterative deliberation. We used the STEEP (Social, Technological, Economic, Environmental, Political) framework (Innovation Research Interchange, 2018) to longlist developments with potential effects on future pathways of European agricultural regions. The STEEP framework is a tool used in the field of futures studies, used to help organizations to identify future developments of relevance. The longlist contains 19 trends (SI-A).

To distill from this longlist of influences a shortlist of spatial megatrends, four selection criteria were used. Megatrends must be (1) credible and relevant for European agricultural futures, (2) dynamic over multi-decadal time scales, (3) spatially heterogeneous across Europe (in accordance with our research goal), and (4) quantifiable with existing data. To assess credibility and dynamism, we analyzed existing foresight and megatrends documents from leading international organizations to find trends recurring across sources and sectors (Allen et al., 2018; Bock et al., 2020; EC, 2017; EEA, 2019; IIASA, 2018; OECD, 2019; WEF, 2021), academic foresight and scenario studies (Iwaniec et al., 2020; Kienast et al., 2019) and companies (BlackRock, 2018; Ernst and Young, 2020; PwC, 2021). We cross-examined these trends with specific literature on the future of European agriculture and the drivers of change in this sector (Jepsen et al., 2015; Levers et al., 2018a; Mitter et al., 2020; Stürck et al., 2018; van Vliet et al., 2015) to filter out trends pertaining strongly to European agriculture.

We subsequently selected those trends for which a spatial signature can be established. A spatial signature can arise because the strength of the megatrend itself varies spatially (e.g. changing agricultural suitability due to climate change) and/or because different places have different levels of sensitivity to this trend (e.g. increasingly stringent environmental regulation is more likely to cause systemic changes in areas with high levels of environmental externalities). The resulting four spatial megatrends are: 1) Climate change; 2) Demographic change; 3) Productivism and post-productivism shifts (denoting changes in the priorities, values, and goals of agricultural and food systems, moving towards a singular focus on high volumes for low prices, or a broader multifunctionality of agriculture, respectively); and 4) Shrinking environmental action space (which captures the dynamic of rising environmental externalities approaching increasingly stringent policy restrictions).

Two megatrends that are credible, relevant, and dynamic, but not strongly spatially defined or quantifiable with existing data, were dropped: technological innovation and changing lifestyles. While these megatrends will generate systemic changes and pressures, their geographic manifestations remain highly speculative.

2.2. Megatrend mapping

Because megatrends and their effects are complex, they need to be quantified and mapped from multiple perspectives. There usually is not one single parameter that can fully capture a megatrend. We mapped the trends themselves, but also the effects of the trend that are observable today or the places where the trend is most likely to have an impact. The EU NUTS-2 regions were used as mapping units where possible.

2.2.1. Climate change

We captured the impacts of climate change on European agriculture by summarizing potential yield trends of the most common European crops, and drought risk trends. This focus on potential yields and droughts is a partial assessment only. Droughts are argued to be the most significant wide-scale climate risk for agriculture (Olesen et al., 2011), other climate risks, such as sea level rise, are not captured because their effects are highly localized (e.g. floods), or not sufficiently understood at the continental scale (e.g. hailstorms).

Potential yield is the highest attainable yield under optimal management, given local biophysical constraints. Trends were derived from Agri4Cast crop modeling (Duveiller et al., 2017), an ensemble of global circulation models (HADGEM2, MIROC, IPSL) coupled with the WOFOST crop model. Yields are water-limited, assume CO_2 fertilization effects, and do not take failed harvests due to, among others, floods, droughts, hail, or crop diseases into account. Trends are calculated between 2000 and 2050 assuming the RCP4.5 concentration pathway.

The resulting map shows the potential yield percentile of the current crop mix (year 2015) and the percentage potential yield changes between 2000 and 2050. To achieve this, we calculated, for each crop present in the NUTS-2 region, the rank of the potential yield compared to other NUTS-2 regions growing that crop (percentile), and calculated an area-weighed sum of all crops. The overall yield change percentage is the area-weighed sum of the percentage yield change between 2000 and 2050 for all crops. Current regional crop mixes were derived from Agri4Cast data, where this was available (i.e. EU-27). For the United Kingdom, Norway, and Switzerland, crop mixes were derived entirely from OneSoil data (http://onesoil.ai, accessed March 2021). The area-weighed sum method implies that regional crop importance is reflected by area, not value. The map reflects climate pressures on the current crop mix, not the option space to change to different crop mixes.

Drought risk is derived from future drought hazard and current local likelihood of drought impacts on agriculture. Future drought hazard trends were derived from RCP4.5 drought projections by Spinoni et al. (2018). Agricultural drought vulnerability is the likelihood that a drought event has a negative impact on the agricultural sector, as calculated by Stahl et al. (2016) based on impact reports in the EDII database (http://europeandroughtcentre.com). The map shows NUTS-2 regions where the number of drought events is projected to be at least 0.7 events per decade higher in 2041–2070 compared to 1981–2010, and the likelihood of impact (vulnerability) is over 50%. These thresholds were set in accordance with input data possibilities (for hazard) and arbitrarily (for vulnerability).

2.2.2. Demographic change

Demographic changes likely to pressure the agricultural sector are the ageing of farmers and the decline of working-age population (Zagata and Sutherland, 2015). We mapped trends in the age distribution of farmers between 2005 and 2016 at NUTS-2 level. For visualization, we classified this data in quartiles and according to the direction of the trend. Furthermore, we mapped regions where the working-age population is declining by 1% or more annually, based on population trends between 2014 and 2020 (UK: 2014–2019). Data sources are EUROSTAT (2021), BFS (2021) and SSB (2021).

We additionally visualize demographic projections until 2100 at NUTS3 and national level, for the general population. We map the evolution of the median age and the share of the population of working age, using baseline projections by Europop2019 (EUROSTAT, 2021).

2.2.3. Productivism and post-productivism shifts

We captured two on-going transformations that contribute to a megatrend of value shifts in agriculture: the productivism shift and the post-productivism shift. Productivism is a value system which is, in its extreme, singularly focused on high production volumes (from the producer perspective) and low food prices (from the consumer and political perspective). Conversely, post-productivism is a value system where multiple values of agricultural land use are considered, which is expressed in the adoption of alternative farming systems and shifting consumer preferences for more sustainable products. Productivism is quantified here in terms of trends in economic farm size and the emergence of very large livestock operations. Post-productivism is highly multidimensional, and is driven by both bottom-up initiatives and top-down political initiatives such as the EU Green Deal. In an effort to capture its manifestation in agricultural systems, we mapped the share of organically certified farmland as a proxy, as there is relatively detailed spatial data available and the increasing of this share is a current EU ambition. Additionally, we summarize the trends between 2012 and 2020 in shares of organic area at the national scale.

Economic farm size quantifies the size of a farm in terms of the value of farm outputs at farm gate price. We quantified the amount of high-output farms for every low-output farm to depict the economic farm size distribution in 2016. A high-output farm is a holding with an economic farm size of 25,000 euro per year. This threshold has been found to be appropriate to distinguish farmers with a stronger market orientation (business farms, agricultural enterprises) from peasants or hobby farmer (Guarín et al., 2020). We mapped the state (2016) and trends (2005 – 2016; Norway: 2005–2013, Switzerland: 2010–2016) in economic farm size ratio, using data from EUROSTAT (2021), BFS (2021) and SSB (2021).

To additionally show the particular dynamics of industrialization of the livestock sector, we mapped the amount of very large livestock holdings. These are individual holdings that have over 500 livestock units, which is the highest category of livestock numbers as classified by Eurostat. A livestock unit corresponds to a specific number of animals, depending on the animal and its rearing purpose. The resulting map is a dot density representation at NUTS-2 level, based on EUROSTAT (2021) data. We additionally visualize the share of livestock raised in megastables, and trends thereof, at the national scale.

Lastly, the share of agricultural area that is farmed under organic management is mapped, based on data from EUROSTAT (2021), BFS (2021) and SSB (2021).

2.2.4. *Decreasing environmental action space*

Agriculture's increasing generation of negative environmental externalities, combined with the decreasing leeway given to such externalities by policies and regulations, is captured under the denominator of environmental action space. We listed the targets that are currently either in place or being announced in the EU's Effort Sharing Regulation (greenhouse gas targets) and the Farm2Fork strategy (European Union, 2020). While these targets do not apply to non-EU countries, the countries covered in this analysis either have agreed to abide by EU regulations or have very similar targets. The trend is the product of both the externality and the regulation thereof. Regulations have become more stringent throughout the last decade (as evidenced by the increasing trend in the Environmental Stringency Index of the OECD (2016), see SI-E for an analysis). Announced policies are set to increase stringency even further (European Commission, 2020). The pressures of these regulations are assumed to fall mostly on regions with high current levels of externalities.

The Farm2Fork strategy lists specific targets relating to nutrient excesses, pesticides, antimicrobial resistance, and greenhouse gas emissions. We assessed these four aspirations spatially to find out where current agricultural systems are potentially under pressure from these signaled or implemented targets. Note that we do not map the shrinking of environmental action space directly, as this is not readily quantifiable, but rather show areas where this action space is very small already, in relation to existing or announced policies. We assume that those systems which currently have high externalities compared to an aspirational target will be under higher pressure to change. Excess nutrients was approximated by the soil surface surplus of nitrogen, pesticide use was derived from the PEST-CHEMGRIDS database (Maggi et al., 2019), and antimicrobial use is mapped using data from the European Medicines Agency. Targets for excess nutrients and pesticide use were calculated as the maximum excess or use for the 2030 aspirational Farm2Fork targets to be attained, assuming all agricultural land is entitled to an equal level of nutrient excess or pesticide use. For antimicrobial use, a widely recognized target of 50 mg per kg of animal product was set. More details on the data sources and processing are given in SI-B.

To assess to what extent efforts to reduce greenhouse gas emissions could pressure agricultural systems, we deployed a three-step approach. We assume that agricultural systems in a specific country will be under pressure if (1) the emission intensity of the agricultural sector (CO_2-eq/ha) is high (*intensity*), (2) the agricultural sector in the country produces a significant share of its total emissions (*share*), and (3) the country is not on track to meet its stated overall greenhouse gas emission reduction targets (*progress*). Indicators for intensity, share, and progress are calculated (see SI-B for all data, procedures, and assumptions).

Based on these three indicators (intensity, share, progress), we calculated a pressure score by adding the min–max normalized indicators for each country (where progress is ahead of schedule, that score is zero). A high compound score indicates a high pressure on agriculture to reduce its greenhouse gas emissions.

2.3. *Horizon scanning*

We used a literature-driven approach to assess the potential of specific megatrend manifestations to generate specific systemic outcomes. We distinguish three broad systemic outcomes: persistence, marginalization, and systemic change.

Persistence is defined as the regional agricultural system's ability to resist or easily recover from perturbations without losing systemic traits and functionality (Filatova et al., 2016). Persistence is the consequence of strong negative feedbacks and a high capacity for internal adaptation, and is equivalent to a lock-in (Oliver et al., 2018). We assume that a megatrend contributes to systemic persistence when current negative feedbacks that maintain regional farm system structure are reinforced.

Systemic change is used here as an umbrella term to capture the transformation of the regional farm system, meaning that a significant share of the primary factors of production (land, labor, capital) are altered. Contrary to persistence, systemic change results in a system with new systemic traits and functionality. The exact shape systemic change can take depends strongly on the particular interference of megatrends, and on the governance and policy priorities in place. Labor shortages driven by population ageing can for example be addressed by a switch to automation, or by Californization (the use of cheap migrant labor in agriculture). We assume that a megatrend contributes to systemic change if it either undermines current regional farm system functioning, prompting a switch to a different, functional system, or provides new opportunities which can be reaped through the switch to an alternative system.

Marginalization is defined as the process by which current regional agricultural systems cease to be viable in their current physical and socio-economic structure (van der Sluis et al., 2016). Marginalization is a specific systemic change. It can result in land abandonment, gradual impoverishment, and/or a reorientation towards non-agricultural systems. We assume that a megatrend contributes to marginalization if it significantly undermines current regional farm system functioning by, among others, generating scarcity in key inputs or increasing risk.

We linked specific megatrend manifestations with persistence, systemic change, and marginalization outcomes based on a literature-based horizon-scanning analysis. We gathered existing literature on drivers of agricultural land system change, resilience and adaptation. Cited studies are systematic reviews or use modeling and statistical inference to establish causal links and mechanisms. This megatrend – outcome table serves to identify the plausible futures of regional farm systems in Europe. A table with outcomes for each megatrend manifestation, and supporting literature, is given in SI-C. This table is subsequently used to perform a simple count of the amount of pressures towards each outcome, and the megatrends they relate to. This is visualized and used to guide the discussion of our results. This summarizing exercise relies heavily on assumed thresholds. When scientific arguments exist for the use of a specific threshold, we used this. In other cases, we used the highest or lowest quartile.

3. Results

3.1. *Climate change*

Previous studies have indicated that climate change impacts in Europe will, in general, cause a northward shift of agro-climatic zones (Ceglar et al., 2019), increasing crop suitability in northern areas, and decreasing suitability in southern areas (Bindi and Olesen, 2011). However, these general patterns are highly crop- and context-specific, and characterized by high uncertainties (Knox et al., 2016).

Fig. 1 shows where climate change is projected to either increase or decrease the potentially attainable yields of the currently-grown crops, as well as future drought risk dynamics. Potential yields are projected to increase in most European regions, with strongest percentage increases found in the UK, the Netherlands, Norway, and higher-elevation regions such as Switzerland and parts of Austria. In these regions, the growing season lengthens as temperature rises. However, increasing drought risk may partly cancel out these positive trends, for example in highly productive regions in Belgium, Germany, and England. Negative potential yield trends in combination with exacerbating drought risks are found in Portugal.

Where conditions improve for current crop mixes, this can contribute to make current systems more persistent, as they remove incentives to consider systemic changes. Alternatively, improving conditions may also trigger systemic changes when they increase the scope for intensification or agricultural industrialization (van der Sluis et al., 2016). In regions faced with negative potential yield trends and/or increasing drought risk, climate change may contribute to systemic change, if adaptation measures are feasible. Such adaptation could include crop mix changes, irrigation, or other management changes (Leclère et al.,

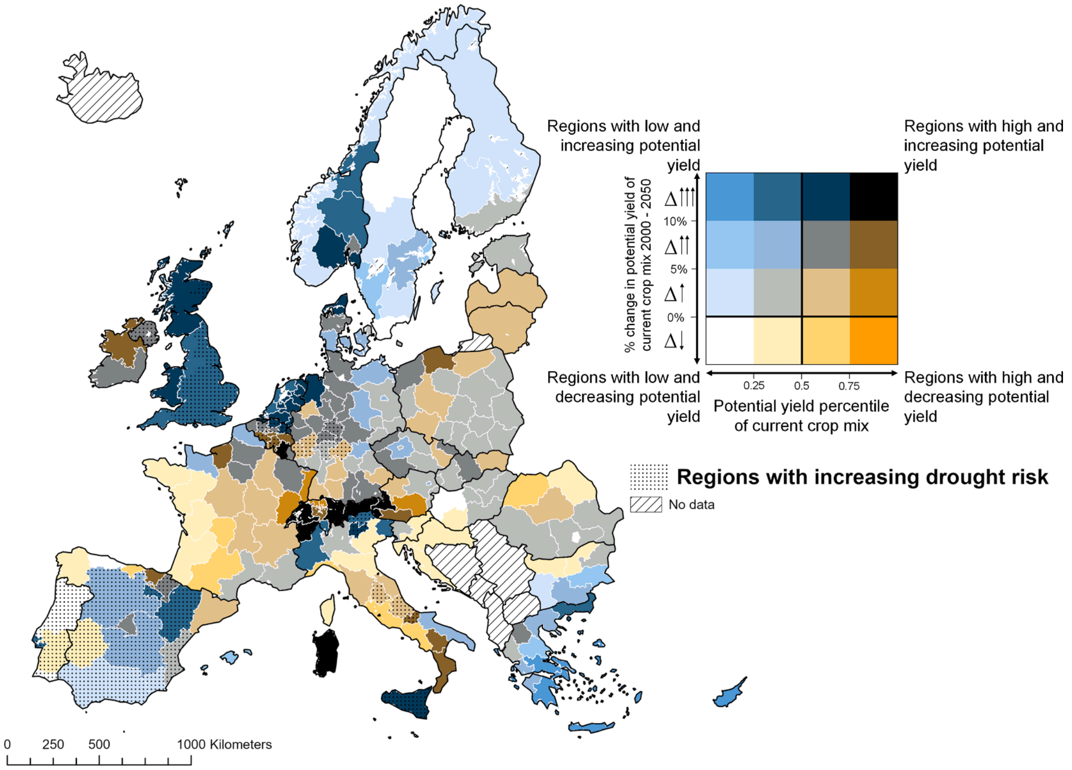


Fig. 1. Climate change megatrend. Colors indicate the levels (in 2015) and changes (between 2000 and 2050) in potential yield, assuming CO_2 fertilization effects, for the current regional crop mix. Colors do not inform on the potential to change to different crops mixes, and do not capture impacts of some meteorological extremes such as hailstorms or floods. Colors on the right-side of the quadrant have high potential yields for the crops they grow currently, relative to other regions in Europe growing these crops, and vice versa on the left side of the quadrant. The bottom row of the quadrant depicts areas where potential yields of currently grown crops are projected to decrease. Dotted regions are regions where drought risk is modelled to increase (increasing hazard combined with high vulnerability, see methods). Note that an increase in crop disease pressure is not taken into account, making yield projections optimistic. Data: Agri4Cast, Spinoni et al. (2018); Stahl et al. (2016), OneSoil.ai. Crop mix data consists of maize, wheat, barley, sugar beet, potato, rye, rice, field beans, and sunflower.

2014; Wens et al., 2019). Where these are not feasible, negative yields trends and droughts can contribute to marginalization (Stürck et al., 2018).

Because of data limitations and uncertainties, this analysis omits specific crops which can be highly significant in specific regions (e.g. vineyards, grasslands), as well as a wide range of extreme meteorological events such as hailstorms, or floods. While drought is identified to be the preeminent climate risk pressure for agriculture in Europe (Olesen et al., 2011), these other risks can locally increase yield variability. Our results are therefore somewhat optimistic. Drought risk estimates are limited by the reporting bias in drought vulnerability assessments, which may cause an underestimation in eastern Europe. Lastly, recent work by Chaloner et al. (2021) strongly suggests that new and amplified plant disease pressures in a warmer climate could temper or even nullify any yield gains resulting from longer growing seasons.

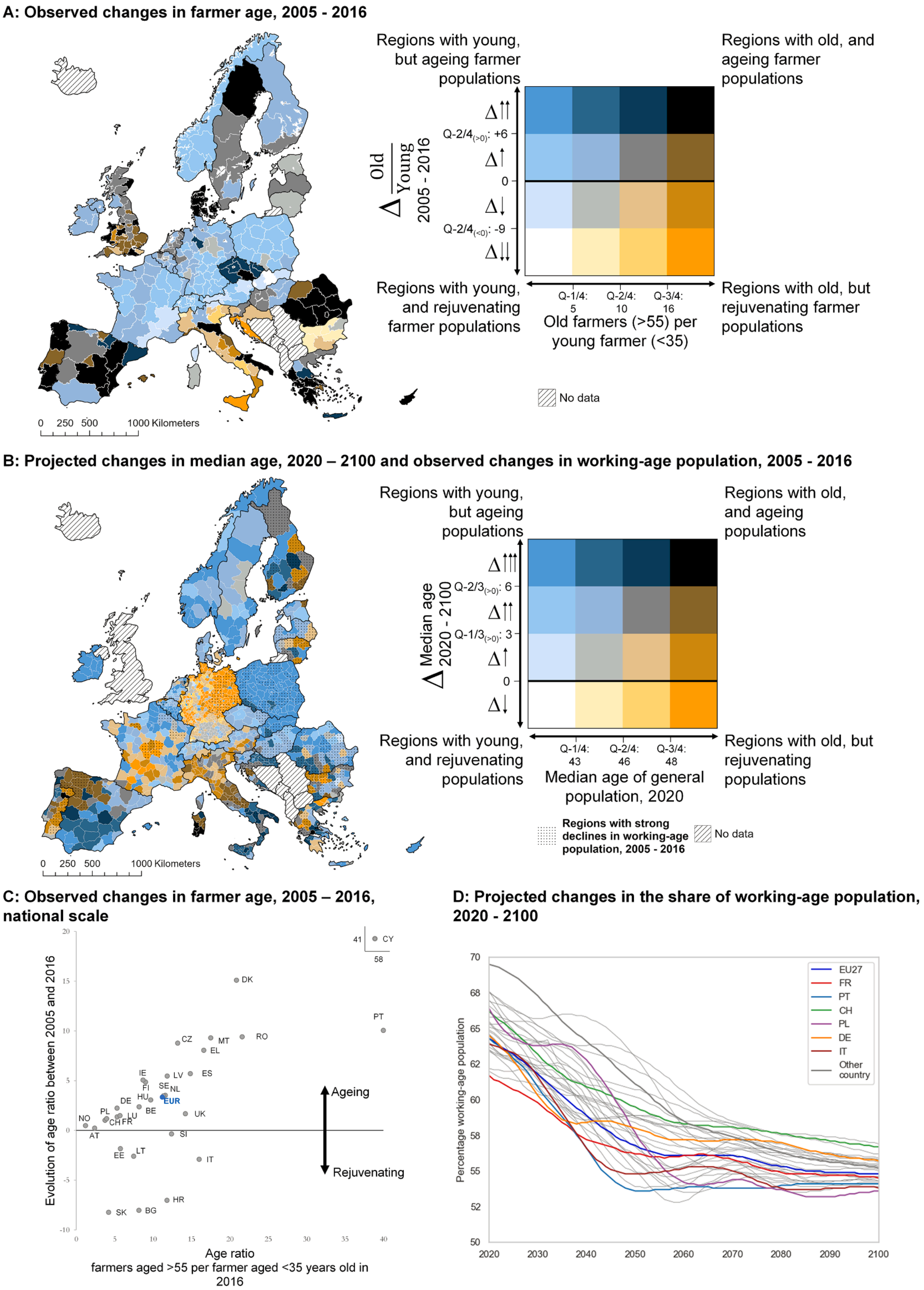
3.2. Demographic change

Europe is the oldest continent in the world, and continues to age, especially in rural areas (Burholt and Dobbs, 2012). The share of the EU population over 55 years old is 32%, and is projected to increase nonlinearly to 41% by 2050. This trend is reconfiguring European societies and will present economic, labor market, and social challenges (EUROSTAT, 2019). The population of European farmers is ageing faster than the European average because, on top of general demographic drivers (low birth and mortality rates), generational renewal is hindered by, among other factors, difficulties acquiring land and often poor economic prospects (Eistrup et al., 2019). This “young farmer problem” is reaching concerning levels and is receiving EU and national policy attention (Zagata and Sutherland, 2015). The particularly fast ageing of rural populations beyond the farmers themselves, driven by urbanization, additionally strains agricultural systems as labor supplies decline, culminating in “youth deserts” in parts of eastern Germany, Spain, France, Italy, Greece, and Bulgaria (Oltermann et al., 2020).

Figure 2-A and -C shows the state and trends in farmer age at the regional level (colors). Particularly grey farmer populations are found on the Iberian peninsula, Denmark, Cyprus, Italy, Croatia, England, and Romania. Trends are dominantly towards further ageing, although regional differences are important. Croatia and parts of Italy are rejuvenating a highly aged farmer population, while Slovakia and Bulgaria have young and rejuvenating farmer populations. Particularly fast farmer ageing takes place in, among others, Portugal, Denmark, Czechia, Romania, and Greece. Steep declines in working-age populations are scattered over the continent, with areas characterized by youth emigration (Romania, Bulgaria, east Germany) particularly visible. Farmer rejuvenation is observed most prominently in Slovakia, Bulgaria, and Croatia.

Fig. 2-B shows projections of the median age of the general population at NUTS-3 level. Few regions are expected to rejuvenate, and of those who do, most currently already have some of the oldest populations and have undergone steep declines in working-age population in the last decades (e.g. eastern Germany, central France). Most regions are expected to see rapid aging (an increase of over 6 years by 2100), coming from a relatively young baseline (bright blue in Fig. 2-B, e.g. Poland, Sweden, Norway, Ireland, Slovakia, and parts of the Benelux). Other regions are expecting similar ageing, but from already old baselines (e.g. northwestern Spain, southern Italy, and parts of Greece and Finland).

An ageing farmer population can be a sign of ongoing or impending marginalization: multiple studies on land abandonment relate the



A: Observed changes in farmer age, 2005 - 2016

B: Projected changes in median age, 2020 – 2100 and observed changes in working-age population, 2005 - 2016

C: Observed changes in farmer age, 2005 – 2016, national scale

D: Projected changes in the share of working-age population, 2020 - 2100

Fig. 2. Demographic megatrend. (A) Map showing farmer ageing. Colors indicate regional age distribution of farmers as the amount of old (>55) farmers for every young farmer (<35) in 2016, and the trends thereof between 2005 and 2016, at NUTS-2 level. (B) Map showing projected changes in median age of the general population at NUTS-3 level. Data for the UK is not available. Colors indicate the median age in 2020 and the projected change in median age according to Europop2019 baseline projections. Dotted areas are regions where the population of working age (15–54 years old) has declined by > 1% annually between 2005 and 2016. (C) National-scale farmer demographic trends. (D) National-scale projections of the percentage of the population of working age (15–64 years old), with selected countries highlighted. Data: Eurostat, BFS, Statbank.

process of terminating agricultural production with diminishing economic viability (Benayas et al., 2007; Terres et al., 2015). Ageing can also drive systemic changes in the form of land consolidation and landscape polarization: exiting farmers disintensify and ultimately transfer their land to fewer, but more intensive consolidator farms (Schulp et al., 2019). Moreover, studies identify farmer ageing as a source of persistence, as older farmers are less likely to change farming practices (Hamilton et al., 2015). Their membership of a cohort of farmers who have mostly farmed under strongly productivist agricultural governance makes them less likely to, for example, adopt organic practices or enroll in environmental programs (Zagata and Sutherland, 2015). This conservative attitude is further enhanced by their later stage of life, which takes away the business incentives to make large changes, especially in absence of successors (Duesberg et al., 2017). The above implies that, as a megatrend, farmer ageing can alternatively contribute to marginalization, systemic change, or persistence, and the exact outcome is highly context-dependent. Farmer rejuvenation, though rare in Europe, can be a contributor to systemic change. Young farmers are more likely to make drastic farm management changes, both towards more intensive or more diversified systems (Scherer et al., 2018; van Vliet et al., 2015). Younger farmers are, for example, found to be more likely to value sustainability and to adopt organic farming (Zagata and

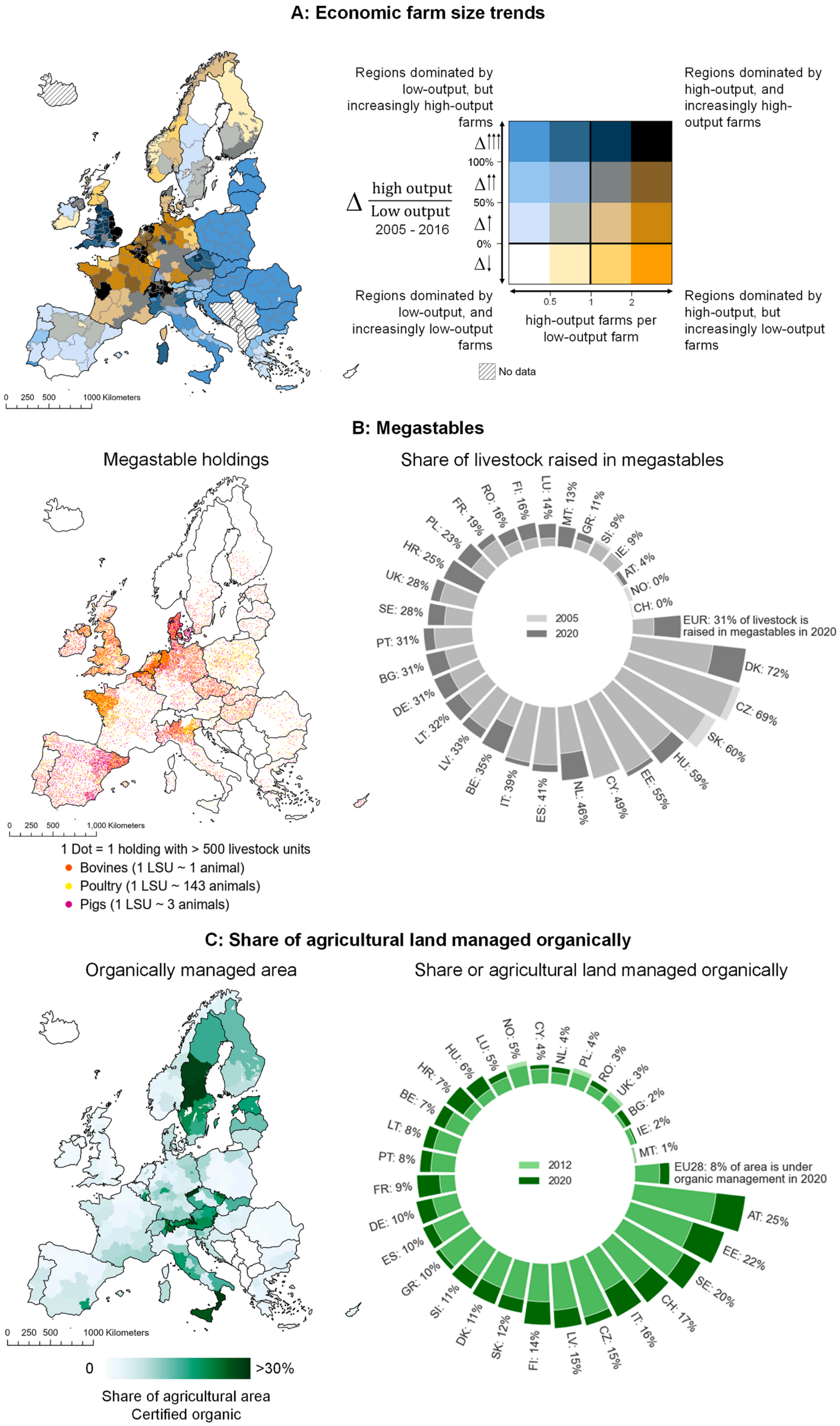


Fig. 3. Productivism and post-productivism shifts. (A) Regional economic farm size distribution and trends thereof. EFS distribution is expressed as the amount of high-output farms (>25000 euro/year) for every low-output farm (<25000 euro/year). (B) density of mega-livestock holdings (dots do not indicate precise location but visualize density) and national-level trends of share of animals raised in mega-livestock holdings. (C) Share of certified organically farmed area and trends national-level trends of share of organically farmer agricultural area. Data: Eurostat, BFS, Statbank.

Sutherland, 2015).

Declines in the size of the working-age population have effects via the labor market. Labor shortages can make farming economically unviable (marginalization). Yet, there are systemic changes to cope with labor shortages: a switch to less labor-intensive systems, automation and robotization (as observed in ageing frontrunner Japan, McGreevy et al. (2019), or Californization, denoting an increased use of migrant labor (Rotz et al., 2019; Zimmerer et al., 2020).

3.3. Productivism and post-productivism shifts

The values underpinning farm and food systems of Europe are changing in two different, and highly contrasting ways: a continued and locally intensified productivism shift, and a relatively recent post-productivism shift (Wilson and Burton, 2015, definitions see Methods). The geography of these two trends is heterogeneous, both because of time lags between regions in embarking on a pathway, and because regions have different abilities and priorities towards either productivism and post-productivism. Productivism, denoting a value system committed to high volumes for low prices above other values and goals (McMichael, 2012), has been dominant in Europe since the second world war, but may be escalating locally. The number of small farms is dropping sharply and land is being concentrated into fewer, more industrialized holdings (van der Ploeg et al., 2015). This new model is alternatively called “productivist”, “specialized”, “industrialized” or “entrepreneurial”, and is closely linked with general globalization trends (Rivera et al., 2020; Robinson, 2018).

Small farms are not disappearing entirely, but the newer generation of small farms can be typified less as peasants, and more as entrepreneurial businesses, often working under contracts with processors or supermarkets (Guarín et al., 2020; Otsuka et al., 2016). Meanwhile, the agri-industry is consolidating horizontally and vertically through mergers of transnational corporations, resulting in a more integrated agricultural value chain (Folke et al., 2019). A result of this is that power and agency in agriculture is shifting to corporate decision-makers (Debonne et al., 2021). However, regional differences emerge as the shift to industrialized agriculture is not manifested homogeneously.

Parallel to a productivism shift, a post-productivism shift is also taking place (Wilson and Burton, 2015). In post-productivist agriculture, values of multifunctionality, place-rootedness, and ecological sustainability are (re-) appraised (Garrett and Rueda, 2019), creating new but fast-growing farm management strategies, notably organic farming (Malek et al., 2019).

While the shifts to productivism and post-productivism are both highly multidimensional, the proxies mapped in Fig. 3 reveal a number of distinct spatial patterns. Economic farm size is a measure of the monetary output of a farm, which has been found to be a key factor to distinguish farmers with a stronger market orientation (business farms, agricultural enterprises) from peasants or hobby farmers (Guarín et al., 2020). The majority of European regions are dominated by relatively low-output farms (<25000 euro/year in this study), although northwest Europe (especially Switzerland and the Benelux) have a strong dominance of large farms (Fig. 3-A). While regional differences are visible in the tempo of economic farm size increase, the trend is almost universally towards higher-output farms. The fastest increases are found in new (2004) EU member states such as Bulgaria, the Baltic states, Slovakia, or Poland (for a national-scale summary of trends, see SI-D). In these regions, which are still dominated by low-output farms, this rapid shift can be interpreted as a sign of systemic change, as large farms are rapidly replacing small farms. Only the Nordic states and Ireland have somewhat stable trends, and Cyprus saw a slight decrease in the amount of high-output farms per low-output farm. Surprisingly, regions with the highest dominance of high-output farms (Switzerland, the Benelux, and England) are all facing strong continued progress towards even larger economic farm sizes, which, in these cases, is a sign of persistence of a highly productivist system. Conversely, regions showing a decrease or very slow increase in economically large farms interpreted as moving towards marginalization. For other outcome interpretations, see SI-C.

Very large livestock holdings (Fig. 3-B), known as megastables (Breeman et al., 2013), are holdings with 500 or more livestock units (1 livestock unit is approximately 1 bovine, 3 pigs, 143 poultry). Such holdings are a hallmark of industrial agriculture and where they cluster regionally, this is interpreted as a sign of systemic change. Fig. 3-B shows where megastables are located and clustered in Europe. In Denmark, 2330 holdings, 11% of all livestock holdings, are megastables, a number that is decreasing in the past decade as megastables merge among themselves. In other megastable agglomerations, notably the Netherlands and Belgium the amount and share of megastables is increasing rapidly (by 34% and 71% between 2005 and 2016, respectively, Eurostat 2021). A regional perspective highlights subnational clusters in, among others, Catalonia (ES), Bretagne (FR), Lower Saxony (DE), and North Rhine Westphalia (DE). Fast increases in the amount of megastables are found in Germany, Poland, Sweden, and France. Zooming in on the share of livestock raised in megastables (Fig. 3-B, right) highlights that megastables are the dominant livestock system in Denmark, Czechia, Slovakia, and Hungary, while they are absent in Switzerland and Norway (as per local regulations) and very rare in Austria.

Post-productivism is partially captured by the shift to organic farming (Fig. 3-C). This shift is highly advanced in specific regions, and has barely taken off in most others. With the exception of the United Kingdom, Poland, and Norway, organic area shares have increased between 2012 and 2020, and this increase has been substantial in regions which are already frontrunners (e.g. Estonia, Italy, Austria, and Switzerland). In the Salzburg region (AT), 52% of used agricultural area is farmed organically. In Calabria (IT), Sicily (IT), East Switzerland, central Sweden, and Moravia-Silesia (CZ), shares of organically farmed land exceed 25%, meeting an aspirational target set out in the EU’s Farm2Fork strategy (European Union, 2020). In contrast to these frontrunner regions, organic area in most European regions does not exceed 5%. Large shares of organically farmed areas are interpreted as a sign of systemic change. Framing these farms as signals of post-productivism does not imply that they are not productive, entrepreneurial, or profit-oriented. Post-productivism is a value system, and the fact that these farms and business opportunities for these value chains emerge signals that consumer and producer values are shifting.

3.4. Environmental action space

The intensification and scale enlargement associated with agricultural methods to attain higher land and labor productivity are increasingly at odds with environmental targets and societal priorities (Campbell et al., 2017; Gerten et al., 2020). EU agriculture emits 511 Mt CO_2-equivalents per year, which constitutes 10% of the EU’s total emissions and remains relatively stable despite a need for significant emission reductions (European Environment Agency, 2018). Moreover, the externalities of progressively intensifying agriculture include soil degradation, water contamination, antibiotic resistance, and biodiversity losses (Gould et al., 2018; Helfenstein et al., 2020; Van Boeckel et al., 2017).

In response to these stressors, environmental regulations have become more stringent (see SI-E for an analysis of the evolution of stringency of environmental policies in the past decades based on OECD, 2016), a trend which is signaled to continue in Europe (Butler, 2018; European Union, 2020). This increasing stringency limits the environmental action space of farmers, who are required by the wider society to operate within specific margins and fulfill new roles as stewards of landscapes.

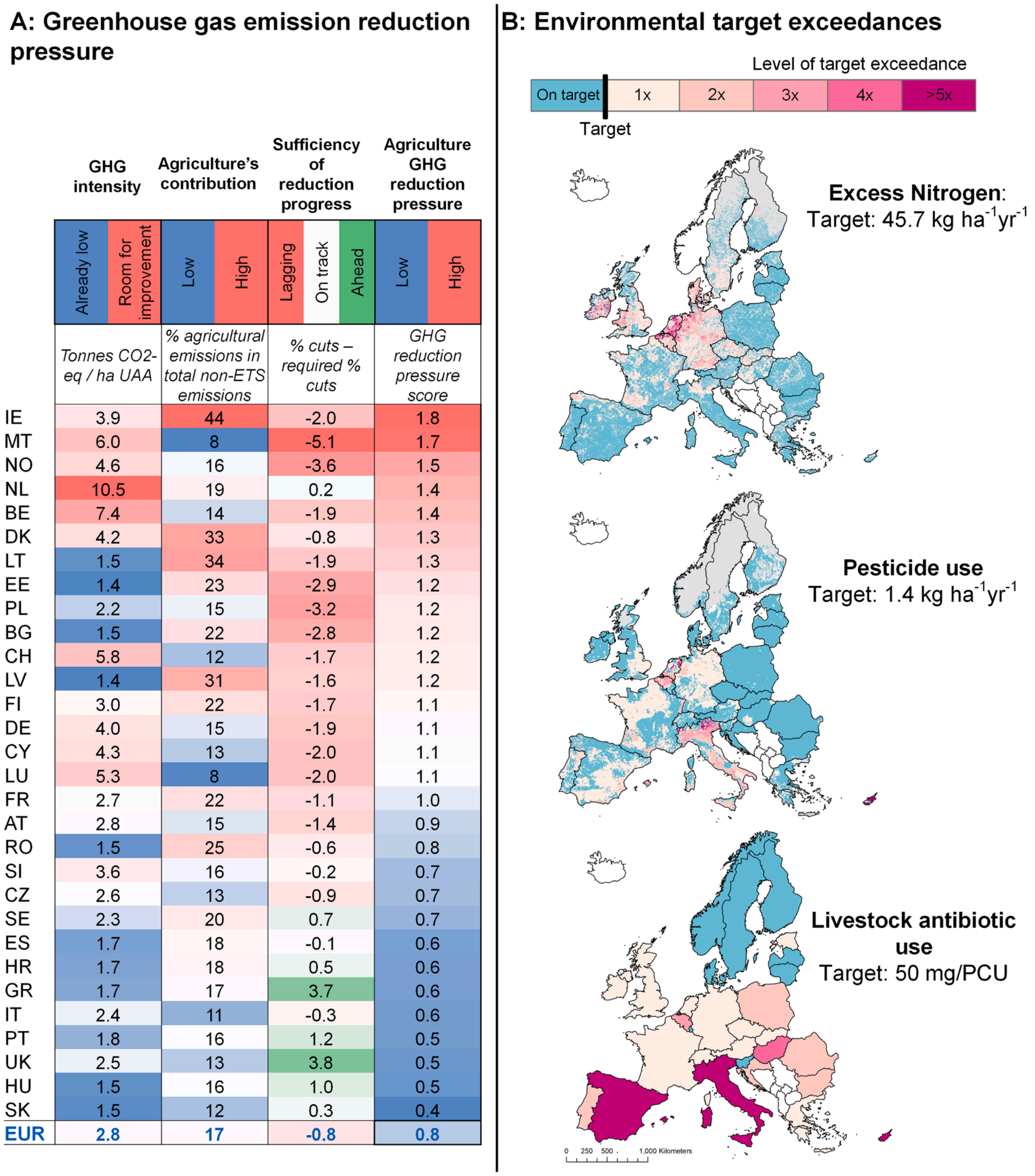
The shrinking of environmental action space is assumed to contribute to systemic change in those regions which are currently characterized by high externalities. Regions where agriculture is having major environmental impacts, in excess of policy targets, are more likely to hit a ceiling at which point a continued business as usual is deemed unacceptable by society and only major systemic changes are sufficient to mitigate impacts. This is exemplified by the nitrogen crisis in the Netherlands and Flanders (BE), where structurally excessive nitrogen emissions, caused largely by the livestock sector, are leading to de-facto moratoria on new large-scale livestock operations and the possible managed downscaling of the livestock sector as a whole (van der Ploeg, 2020).

Fig. 4 visualizes the current environmental performance of agriculture, relative to the priorities that have bearing on farming practices, set out in the Farm2Fork strategy (European Union, 2020). These priorities are the reduction of greenhouse gas emissions, excess nitrogen, pesticide use, and livestock antibiotics use.

Figure 4-A presents a greenhouse gas emission reduction pressure score, a compound index which is a function of the greenhouse gas intensity of agriculture (emissions per hectare), the contribution of the agricultural sector to the total non-tradeable emissions, and the sufficiency of emission reduction progress. The latter measures the current speed of non-tradeable emission reductions to the required emissions reduction speed if 2030 targets are to be met.

Ireland is found to have the highest greenhouse gas reduction pressure, owing in large part to the fact that agriculture constitutes 44% of non-tradeable emissions. Malta and Norway face high pressures as their progress is too slow; in the case of Norway, this is related to their particularly ambitious 2030 target (40% reduction relative to 2005). For the Netherlands and Belgium, the pressure score is high due to a particularly emissions-intensive agricultural sector.

Fig. 4-B shows the regions or countries where current environmental performance does not meet aspirational targets. For antibiotic use, this target is a widely-recognized figure, and for excess nitrogen and



A: Greenhouse gas emission reduction pressure

	GHG intensity	Agriculture's contribution	Sufficiency of reduction progress	Agriculture GHG reduction pressure
	Already low – Room for improvement	Low – High	Lagging – On track – Ahead	Low – High
	Tonnes CO2-eq / ha UAA	*% agricultural emissions in total non-ETS emissions*	*% cuts – required % cuts*	*GHG reduction pressure score*
IE	3.9	44	-2.0	1.8
MT	6.0	8	-5.1	1.7
NO	4.6	16	-3.6	1.5
NL	10.5	19	0.2	1.4
BE	7.4	14	-1.9	1.4
DK	4.2	33	-0.8	1.3
LT	1.5	34	-1.9	1.3
EE	1.4	23	-2.9	1.2
PL	2.2	15	-3.2	1.2
BG	1.5	22	-2.8	1.2
CH	5.8	12	-1.7	1.2
LV	1.4	31	-1.6	1.2
FI	3.0	22	-1.7	1.1
DE	4.0	15	-1.9	1.1
CY	4.3	13	-2.0	1.1
LU	5.3	8	-2.0	1.1
FR	2.7	22	-1.1	1.0
AT	2.8	15	-1.4	0.9
RO	1.5	25	-0.6	0.8
SI	3.6	16	-0.2	0.7
CZ	2.6	13	-0.9	0.7
SE	2.3	20	0.7	0.7
ES	1.7	18	-0.1	0.6
HR	1.7	18	0.5	0.6
GR	1.7	17	3.7	0.6
IT	2.4	11	-0.3	0.6
PT	1.8	16	1.2	0.5
UK	2.5	13	3.8	0.5
HU	1.5	16	1.0	0.5
SK	1.5	12	0.3	0.4
EUR	**2.8**	**17**	**-0.8**	**0.8**

B: Environmental target exceedances

Fig. 4. Environmental action space megatrend. (A) Agricultural greenhouse gas emission reduction pressure calculation and score. The score quantifies the pressure on the agricultural sector to reduce its emissions, based on (1) the emission intensity of agriculture (emissions per hectare), (2) the share of agriculture in all non-tradeable emissions, and (3) the discrepancy in annual emission reduction progress compared to the annual progress required to meet 2030 binding targets. The score is the sum of the min–max normalized constituents, where positive progress sufficiency is counted as zero. Higher scores indicate that the agricultural sector is under more pressure to reduce emissions. (B) Environmental performance of regions and countries in terms of excess nitrogen, pesticide use, antibiotic use, compared to an aspirational target (see methods for target-setting procedures).

pesticide use, the Farm2Fork-aspired 50% reduction goal is used to derive a 2030 budget, which is equally distributed over the European agricultural area (see methods).

35% of agricultural area in Europe (excl. Switzerland, Norway and Croatia) exceeds the target of 45.7 kg $ha^{-1}yr^{-1}$ of excess nitrogen, and for 11% of area, excess nitrogen more than doubles the target. Note that excess nitrogen does not equal nitrogen input (fertilizers, manure), but rather the leftover nitrogen not retained by plants, which causes the environmental issues being regulated (e.g. eutrophication). For Malta, the Benelux, and Denmark, virtually all agricultural areas are in excess, and especially in the Netherlands, 80% of area has a double exceedance.

A pesticide use target of 1.4 kg $ha^{-1}yr^{-1}$ is exceeded on over 75% of agricultural land in Cyprus, Italy, Germany, Belgium and the Netherlands. Except for Germany, the aforementioned countries all have particularly high levels of exceedance (double or more). This is in stark contrast with the Nordic, Baltic, and most Eastern European countries, where virtually no exceedance is found. Note that pesticide use is not equal to pesticide risk, and a sum-total of pesticide use can obscure the different health- and biodiversity impacts of different pesticide ingredients.

Average livestock antibiotic use is far-above the 50 mg/PCU target in Cyprus, Italy, Spain, and Hungary, and to a lesser extent in Belgium, Poland, Croatia, Romania and Bulgaria. This high average dosage is typically caused by high livestock densities, excessive preventative treatment, and a failure to invest in alternative disease prevention techniques. Surprisingly, Denmark, a country with a very intensive

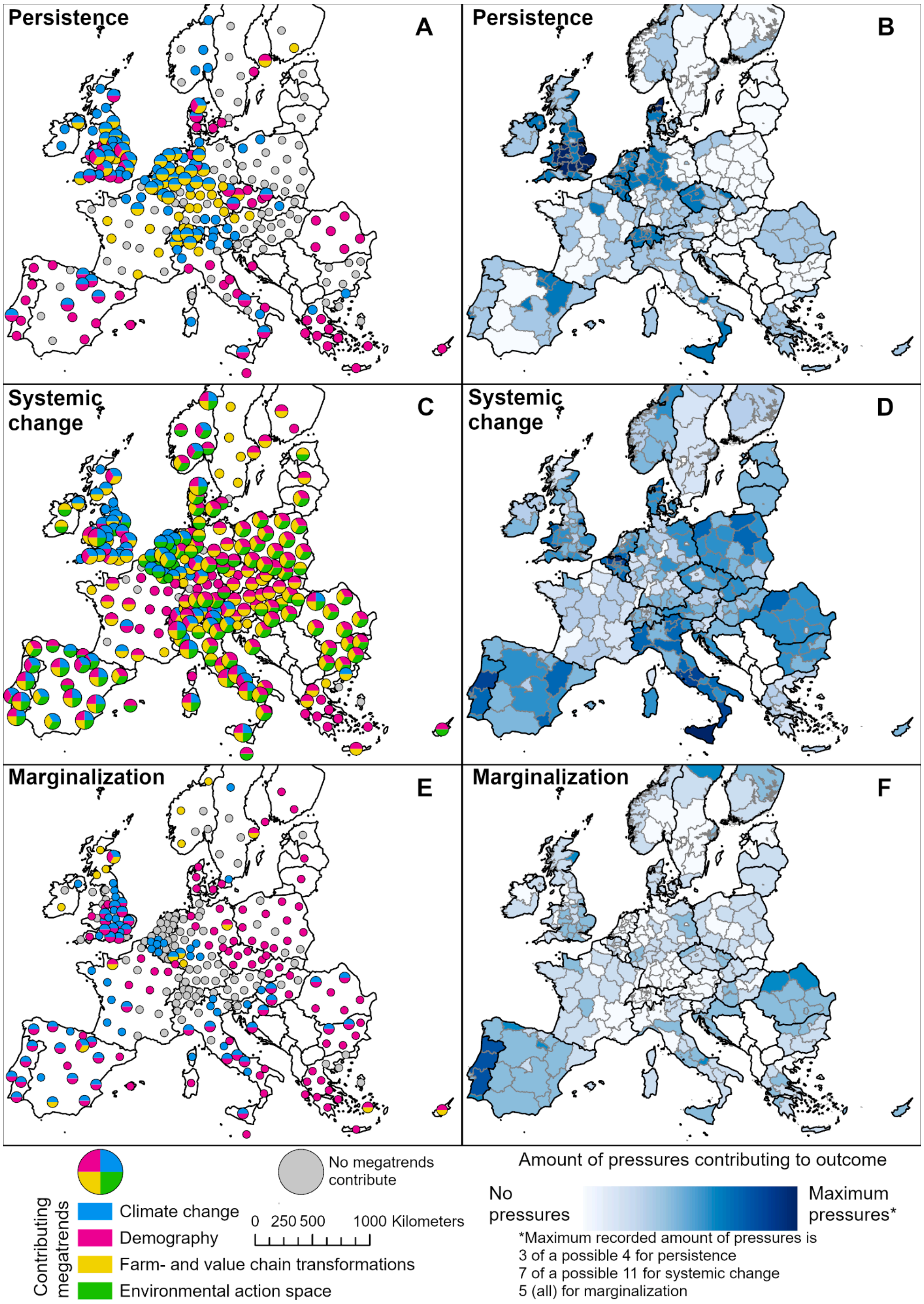


Fig. 5. The geography of megatrends contributing to or signaling persistence, systemic change, and marginalization. Left panels show, for each NUTS-2 region, the specific megatrends that contribute to persistence, systemic change, or marginalization (grey if none). Right panels show the amount of individual pressures contributing to, or signaling the outcome, which is a measure of the degree to which pressures combine towards the outcome. Note that a megatrend is constituted of multiple pressures, and that a single pressure may have multiple possible outcomes.

livestock sector, is among the countries that meet the target.

4. Discussion and conclusions

4.1. The geography of megatrends in Europe

Fig. 5 shows a measure of the combined pressure towards persistence, systemic change, and marginalization (right), and the specific megatrends contributing to this pressure (left). This figure is generated using a set of thresholds (SI-C), and is used to guide this discussion. Note that these outcomes are to be understood within a system resilience framework: they are not deterministic results but rather signals of the pressure towards a certain transformation (Bauch et al., 2016). The colors in panels B, D and F show how many pressures contribute to a specific outcome.

Regions where megatrends are pushing towards persistence include Jutland (DK), most English regions, and the Spanish regions of Aragon, Navarra, and the Basque Country. In these regions, current crop mixes are projected to increase in productivity due to climate change, a relatively old and aging farmer population may be less inclined to change practices, and economic farm size trends are continuous.

Systemic persistence has traditionally been deemed desirable, because a maintenance of the current status-quo avoids a redistribution of power and resources and fits the dominant narrative positioning food system stability as a central goal (Ward et al., 2008). The persistence of systems that deliver a high amount of co-benefits to nature and society, such as cultural landscapes, is valued (Lieskovský and Bürgi, 2018). However, the persistence of European agricultural systems is increasingly recognized as being problematic, because of conventional agriculture's significant contributions to climate change, environmental degradation, and socio-economic problematics in rural areas (Bais-Moleman et al., 2019; Knickel et al., 2018). Beyond this desire to break out of persistence to decrease negative externalities and increase co-benefits (Oliver et al., 2018), persistence can also impede much-needed early adaptation to climate change (Leclère et al., 2014).

Almost all European regions have megatrends contributing to or signaling systemic change. This implies that, while there is a large diversity in megatrend contexts, each region has elements of instability in its agricultural system. This is especially so in, among others, Flanders (BE), Sicily (IT), Lazio (IT), Abruzzo (IT), and Central Portugal. These regions face a combination of significant climate change impacts (positive or negative), a highly dynamic demography, substantive shifts towards productivism and/or post-productivism, and high levels of environmental target exceedances. Systemic changes arise mostly from the demographic and value chain megatrends.

The almost omnipresent nature of signs of system instability implies that current agricultural systems are under pressure across Europe, a finding echoed in other foresight studies on European agriculture (Bock et al., 2020). Responses to these pressures can be highly diverse. For example, when responding to drought and ageing, a region can switch to highly automated indoor setups, or dis-intensify and even abandon farming. The systemic change outcome only indicates that the current system is unlikely to persist in its current form, it does not inform on the direction of change because this depends on governance priorities and steering. Regions where megatrends converge towards systemic change face the challenge of identifying desirable changes, and leveraging pressures to actualize them.

Only few regions are found to have multiple pressures towards marginalization, driven mostly by climate change or high degrees of farmer and population ageing. Especially in most Portuguese regions, marginalization pressures are found in combination (here, drought risk exacerbate the climate and demography pressures). In these regions, governance towards a managed retreat from agriculture may be advisable, or significant adaptation to and mitigation of megatrend manifestations is to be organized.

Marginalization is generally perceived to be a negative outcome that needs to be combatted through rural development policies and various support schemes to build resilience and counteract the developments that undermine system functionality (Nicholas et al., 2015). This is, for example, the explicit goal of the EU's Less Favoured Areas policy (van Zanten et al., 2014). There are valid reasons for such interventions: unmanaged land abandonment can be the source of environmental degradation, the loss of cultural landscapes, and rural community unraveling (Levers et al., 2018b; Schulp et al., 2019). However, there are increasingly calls for a managed retreat from agriculture, which would enable the setting aside of large areas of land in suboptimal regions for nature (Leal Filho et al., 2017). In this way, marginalization can be the starting point for rewilding (Ceausu et al., 2015), eco-tourism (Ioppolo et al., 2013), or other non-agricultural land uses.

Persistence, systemic change, and marginalization are non-specific outcomes by design and should be understood as the future the region is pushed towards to, and not the inevitable destiny of the region. A range of adaptation and capacity building options exist to shape regional futures in the context of rising pressures, and our method only aims to map the direction of pressures. Furthermore, while we have discussed some of the recent discourse surrounding the desirability of persistence, change, or marginalization, the qualification of any outcome as good or bad should be performed in a context-dependent and participatory way. Megatrends can serve to contextualize and delineate such deliberations.

4.2. Spatial foresight use and limitations

By focusing on megatrends with a spatial signature, our analysis emphasizes the different megatrend constellations at play in different regions. This provides two key takeaways. First, there is a significant diversity in pressures. Some regions in Europe are already highly dynamic, others are locked-in, and still others are struggling to stay viable. In a context where major transformations are needed to address urgent sustainability issues, policy makers should regionally differentiate their strategies with these different megatrend pressures in mind. Second, our analysis shows that, while there are regions where multiple, and sometimes contradictory pressures are converging, there are scant regions that are pressure-free. Only five regions have no pressure towards systemic change. This suggests that, while there are a multitude of plausible futures for European agriculture, a stable business as usual may be among the less plausible.

Similar to other foresight studies, our selection of the four megatrends and the indicators that we chose to analyze have been informed by previously published futures studies, combined with a selection procedure. Other foresight studies have used stakeholder consultation (Oldekop et al., 2020), a method often applied in corporate foresight (Innovation Research Interchange, 2018). A promising next step for foresight studies on European agriculture is the use of participatory methods to list megatrends, and to explore potential implications of megatrends.

We have omitted non-spatial megatrends, because their impacts are difficult to assess at the regional scale. However, non-spatial megatrends will interfere with the spatial megatrends discussed here. These include, among others, technological change (biotech, automation, digitalization), globalization (e.g. free trade agreements), telecoupled effects of global agricultural developments (e.g. global large-scale land acquisitions in the Global South, providing for the Global North), and dietary shifts. All these non-spatial megatrends can and will interfere with our results: they can alleviate or exacerbate the outcomes presented here. For example, technological developments could open up possibilities for an aging, climatically worsening region, turning marginalization into persistence or systemic change. Dietary changes, part of a wider societal change megatrend, could result in lower livestock numbers and eliminate pressures from a shrinking environmental action space. However, alternatively, it could increase these same pressures when diets shift to higher meat demands in a more globalized world. These developments remain understudied, and future foresight studies on European agriculture can elucidate how these non-spatial megatrends generate pressures and outcomes.

In our aim to map and quantify megatrends, we have pragmatically reduced the complexity of these trends. Not all dimensions of megatrends can be expressed in numbers, and low data availability or quality, and a lack of multi-temporal data further limits possibilities to present indicators and proxies. A combination of more qualitative assessments of megatrends and further quantification of hitherto unexplored megatrend dimensions are important next research steps.

Linking megatrends with likely outcomes requires a reliance on assumptions concerning thresholds. The maps in Fig. 5 are therefore presented as a summary discussion point, rather than a definitive result. Different analysts will estimate thresholds in different ways, depending on the goal of the assessment. For example, an analyst interested in early warnings would set thresholds for systemic change outcomes lower, which would increase false positive rates, while an analyst interested in pressure hotspots would do the opposite. Our intention was to present an overview of spatial megatrends, and this goal has informed our choice of thresholds.

CRediT authorship contribution statement

Niels Debonne: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft. **Matthias Bürgi:** Writing – review & editing, Funding acquisition, Project administration. **Vasco Diogo:** Conceptualization, Writing – review & editing. **Julian Helfenstein:** Conceptualization, Writing – review & editing. **Felix Herzog:** Writing – review & editing, Funding acquisition, Project administration. **Christian Levers:** Conceptualization, Writing – review & editing, Data curation. **Franziska Mohr:** Conceptualization, Writing – review & editing. **Rebecca Swart:** Conceptualization, Writing – review & editing. **Peter Verburg:** Conceptualization, Writing – review & editing, Funding acquisition, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was conducted in the project “What is Sustainable Intensification? Operationalizing Sustainable Agricultural Pathways in Europe (SIPATH)”, funded by the Swiss National Science Foundation [grant no. CRSII5_183493] and contributes to the Global Land Programme (GLP) science plan. We thank Veit Blauhut, Swetlana Renner, and Alexander Zorn for providing important datasets used in this analysis. We thank three anonymous reviewers for their constructive comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2022.102551.

References

Allen, B., Bas-defossez, F., Weigelt, J., 2018. Feeding Europe: Agriculture and sustainable food systems.

Bais-Moleman, A.L., Schulp, C.J.E., Verburg, P.H., 2019. Assessing the environmental impacts of production- and consumption-side measures in sustainable agriculture intensification in the European Union. Geoderma 338, 555–567. https://doi.org/10.1016/j.geoderma.2018.11.042.

Bauch, C.T., Sigdel, R., Pharaon, J., Anand, M., 2016. Early warning signals of regime shifts in coupled human-environment systems. Proc. Natl. Acad. Sci. U. S. A. 113, 14560–14567. https://doi.org/10.1073/pnas.1604978113.

Benayas, J.M.R., Martins, A., Nicolau, J.M., Schulz, J.J., 2007. Abandonment of agricultural land: An overview of drivers and consequences. CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 2 https://doi.org/10.1079/PAVSNNR20072057.

BFS, 2021. Farm Structure Survey [WWW Document]. URL https://www.bfs.admin.ch/.

Bindi, M., Olesen, J.E., 2011. The responses of agriculture in Europe to climate change. Reg. Environ. Chang. 11, 151–158. https://doi.org/10.1007/s10113-010-0173-x.

Bisoffi, S., 2019. A meta-analysis of recent foresight documents in support of the 5 th SCAR Foresight Exercise.

BlackRock, 2018. Megatrends - The forces shaping our future.

Bock, A.-K., Krzysztofowicz, M., Rudkin, J., Winthagen, V., 2020. Farmers of the future, Publications of the European Union. Brussels. doi: 10.2760/5237.

Breeman, G., Termeer, C.J.A.M., Lieshout, M.V., 2013. Decision making on mega stables: Understanding and preventing citizens’ distrust. NJAS – Wageningen J. Life Sci. 66, 39–47. https://doi.org/10.1016/j.njas.2013.05.004.

Burholt, V., Dobbs, C., 2012. Research on rural ageing: Where have we got to and where are we going in Europe? J. Rural Stud. 28, 432–446. https://doi.org/10.1016/j.jrurstud.2012.01.009.

Butler, D., 2018. EU expected to vote on pesticide ban after major scientific review. Nature 555, 150–151. https://doi.org/10.1038/d41586-018-02639-1.

Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D., 2017. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecol. Soc. 22 https://doi.org/10.5751/ES-09595-220408.

Carpenter, S.R., Booth, E.G., Gillon, S., Kucharik, C.J., Loheide, S., Mase, A.S., Motew, M., Qiu, J., Rissman, A.R., Seifert, J., Soylu, E., Turner, M., Wardropper, C. B., 2015. Plausible futures of a social-ecological system: Yahara watershed, Wisconsin. USA. Ecol. Soc. 20 https://doi.org/10.5751/ES-07433-200210.

Castro, A.J., López-Rodríguez, M.D., Giagnocavo, C., Gimenez, M., Céspedes, L., La Calle, A., Gallardo, M., Pumares, P., Cabello, J., Rodríguez, E., Uclés, D., Parra, S., Casas, J., Rodríguez, F., Fernandez-Prados, J.S., Alba-Patiño, D., Expósito-Granados, M., Murillo-López, B.E., Vasquez, L.M., Valera, D.L., 2019. Six collective challenges for sustainability of Almería greenhouse horticulture. Int. J. Environ. Res. Public Health 16 (21), 4097.

Ceausu, S., Hofmann, M., Navarro, L.M., Carver, S., Verburg, P.H., Pereira, H.M., 2015. Mapping opportunities and challenges for rewilding in Europe. Conserv. Biol. 29, 1017–1027. https://doi.org/10.1111/cobi.12533.

Ceglar, A., Zampieri, M., Toreti, A., Dentener, F., 2019. Observed Northward Migration of Agro-Climate Zones in Europe Will Further Accelerate Under Climate Change. Earth’s Futur. 7, 1088–1101. https://doi.org/10.1029/2019EF001178.

Chaloner, T.M., Gurr, S.J., Bebber, D.P., 2021. Plant pathogen infection risk tracks global crop yields under climate change. Nat. Clim. Chang. 11, 710–715. https://doi.org/10.1038/s41558-021-01104-8.

Debonne, N., Vliet, J.V., Metternicht, G., Verburg, P.H., 2021. Agency shifts in agricultural land governance and their implications for land degradation neutrality. Glob. Environ. Chang. 66, 102221 https://doi.org/10.1016/j.gloenvcha.2020.102221.

Duesberg, S., Bogue, P., Renwick, A., 2017. Retirement farming or sustainable growth – land transfer choices for farmers without a successor. Land use policy 61, 526–535. https://doi.org/10.1016/j.landusepol.2016.12.007.

Duveiller, G., Donatelli, M., Fumagalli, D., Zucchini, A., Nelson, R., Baruth, B., 2017. A dataset of future daily weather data for crop modelling over Europe derived from climate change scenarios. Theor. Appl. Climatol. 127, 573–585. https://doi.org/10.1007/s00704-015-1650-4.

EC, 2017. EU Agricultural Outlook 2017-2030. doi: 10.2762/715.

EEA, 2019. Drivers of change of relevance for Europe’s environment and sustainability.

Eistrup, M., Sanches, A.R., Muñoz-Rojas, J., Correia, T.P., 2019. A “young farmer problem”? Opportunities and constraints for generational renewal in farm management: an example from southern Europe. Land 8, 1–13. https://doi.org/10.3390/land8040070.

Ernst and Young, 2020. Megatrends 2020 and beyond, EY Report.

European Commission, 2020. Farm to Fork Strategy.

European Environment Agency GHG emissions by sector in the EU-28, 1990–2016 [WWW Document] https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-sector-in 2018 accessed 12.3.20.

European Union, 2020. From Farm to Fork: Our food, our health, our planet, our future.

EUROSTAT, 2021. EUROSTAT European statistics [WWW Document]. URL https://ec.europa.eu/eurostat.

EUROSTAT, 2019. Ageing Europe - Looking at the lives of older people in the EU. doi: 10.1136/bmj.315.7115.1103.

Ewert, F., Rötter, R.P., Bindi, M., Webber, H., Trnka, M., Kersebaum, K.C., Olesen, J.E., van Ittersum, M.K., Janssen, S., Rivington, M., Semenov, M.A., Wallach, D., Porter, J. R., Stewart, D., Verhagen, J., Gaiser, T., Palosuo, T., Tao, F., Nendel, C., Roggero, P. P., Bartošová, L., Asseng, S., 2015. Crop modelling for integrated assessment of risk to food production from climate change. Environ. Model. Softw. 72, 287–303. https://doi.org/10.1016/j.envsoft.2014.12.003.

Fazey, I., Moug, P., Allen, S., Beckmann, K., Blackwood, D., Bonaventura, M., Burnett, K., Danson, M., Falconer, R., Gagnon, A.S., Harkness, R., Hodgson, A., Holm, L., Irvine, K.N., Low, R., Lyon, C., Moss, A., Moran, C., Naylor, L., O’Brien, K., Russell, S., Skerratt, S., Rao-Williams, J., Wolstenholme, R., 2018. Transformation in a changing climate: a research agenda. Clim. Dev. 10, 197–217. https://doi.org/10.1080/17565529.2017.1301864.

Fedele, G., Donatti, C.I., Harvey, C.A., Hannah, L., Hole, D.G., 2019. Transformative adaptation to climate change for sustainable social-ecological systems. Environ. Sci. Policy 101, 116–125. https://doi.org/10.1016/j.envsci.2019.07.001.

Filatova, T., Polhill, J.G., van Ewijk, S., 2016. Regime shifts in coupled socio-environmental systems: Review of modelling challenges and approaches. Environ. Model. Softw. 75, 333–347. https://doi.org/10.1016/j.envsoft.2015.04.003.

Folke, C., Österblom, H., Jouffray, J.-B., Lambin, E.F., Adger, W.N., Scheffer, M., Crona, B.I., Nyström, M., Levin, S.A., Carpenter, S.R., Anderies, J.M., Chapin, S., Crépin, A.-S., Dauriach, A., Galaz, V., Gordon, L.J., Kautsky, N., Walker, B.H., Watson, J.R., Wilen, J., de Zeeuw, A., 2019. Transnational corporations and the challenge of biosphere stewardship. Nat. Ecol. Evol. 3 (10), 1396–1403.

Fuchs, R., Brown, C., Rounsevell, M., 2020. Europe's Green Deal offshores environmental damage to other nations. Nature 586, 671–673. https://doi.org/10.1038/d41586-020-02991-1.

Garrett, R., Rueda, X., 2019. Telecoupling and consumption in agri-food systems, in: Friis, C., Nielsen, J.Ø. (Eds.), Telecoupling. pp. 15–137. doi: 10.1007/978-3-030-11105-2.

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B.L., Fetzer, I., Jalava, M., Kummu, M., Lucht, W., Rockström, J., Schaphoff, S., Schellnhuber, H.J., 2020. Feeding ten billion people is possible within four terrestrial planetary boundaries. Nat. Sustain. 3 (3), 200–208.

Gould, F., Brown, Z.S., Kuzma, J., 2018. Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance? Science (80-.) 360, 728–732. https://doi.org/10.1126/science.aar3780.

Guarín, A., Rivera, M., Pinto-Correia, T., Guiomar, N., Šūmane, S., Moreno-Pérez, O.M., 2020. A new typology of small farms in Europe. Glob. Food Sec. 26, 100389.

Hamilton, W., Bosworth, G., Ruto, E., 2015. Entrepreneurial younger farmers and the young farmer problem in England. J. Agric. For. 61, 61–69. https://doi.org/10.17707/agricultforest.61.4.05.

Helfenstein, J., Diogo, V., Bürgi, M., Verburg, P.H., Swart, R., Mohr, F., Debonne, N., Levers, C., Herzog, F., 2020. Conceptualizing pathways to sustainable agricultural intensification. Adv. Ecol. Res. 1–32 https://doi.org/10.1016/bs.aecr.2020.08.005.

Holman, I.P., Brown, C., Janes, V., Sandars, D., 2017. Can we be certain about future land use change in Europe? A multi-scenario, integrated-assessment analysis. Agric. Syst. 151, 126–135. https://doi.org/10.1016/j.agsy.2016.12.001.

IIASA, 2018. Transformations to Achieve the Sustainable Development Goals - Report prepared by The World in 2050 initiative, TWI2050. https://doi.org/10.22022/TNT/07-2018.15347.

Innovation Research Interchange, 2018. Scanning the STEEP landscape [WWW Document]. SPRING. URL https://irispring.com/learning_modules/module-4-scanning-the-steep-landscape/.

Ioppolo, G., Saija, G., Salomone, R., 2013. From coastal management to environmental management: The sustainable eco-tourism program for the mid-western coast of Sardinia (Italy). Land use policy 31, 460–471. https://doi.org/10.1016/j.landusepol.2012.08.010.

Iwaniec, D.M., Cook, E.M., Davidson, M.J., Berbés-Blázquez, M., Georgescu, M., Krayenhoff, E.S., Middel, A., Sampson, D.A., Grimm, N.B., 2020. The co-production of sustainable future scenarios. Landsc. Urban Plan. 197, 103744 https://doi.org/10.1016/j.landurbplan.2020.103744.

Jepsen, M.R., Kuemmerle, T., Müller, D., Erb, K., Verburg, P.H., Haberl, H., Vesterager, J.P., Andrič, M., Antrop, M., Austrheim, G., Björn, I., Bondeau, A., Bürgi, M., Bryson, J., Caspar, G., Cassar, L.F., Conrad, E., Chromý, P., Daugirdas, V., Van Eetvelde, V., Elena-Rosselló, R., Gimmi, U., Izakovicova, Z., Jančák, V., Jansson, U., Kladnik, D., Kozak, J., Konkoly-Gyuró, E., Krausmann, F., Mander, Ü., McDonagh, J., Pärn, J., Niedertscheider, M., Nikodemus, O., Ostapowicz, K., Pérez-Soba, M., Pinto-Correia, T., Ribokas, G., Rounsevell, M., Schistou, D., Schmit, C., Terkenli, T.S., Tretvik, A.M., Trzepacz, P., Vadineanu, A., Walz, A., Zhllima, E., Reenberg, A., 2015. Transitions in European land-management regimes between 1800 and 2010. Land Use Policy 49, 53–64. https://doi.org/10.1016/j.landusepol.2015.07.003.

Kienast, F., Helfenstein, J., Grêt-Regamey, A., Haines-Young, R., Potschin, M., 2019. Ecosystem Services Under Pressure, in: von Haaren, C., Lovett, A.A., Albert, C. (Eds.), Landscape Planning with Ecosystem Services. Springer, pp. 91–101. doi: 10.1007/978-94-024-1681-7_7.

Knickel, K., Redman, M., Darnhofer, I., Ashkenazy, A., Calvão Chebach, T., Šūmane, S., Tisenkopfs, T., Zemeckis, R., Atkociuniene, V., Rivera, M., Strauss, A., Kristensen, L.S., Schiller, S., Koopmans, M.E., Rogge, E., 2018. Between aspirations and reality: making farming, food systems and rural areas more resilient, sustainable and equitable. J. Rural Stud. 59, 197–210. https://doi.org/10.1016/j.jrurstud.2017.04.012.

Knox, J., Daccache, A., Hess, T., Haro, D., 2016. Meta-analysis of climate impacts and uncertainty on crop yields in Europe. Environ. Res. Lett. 11 (11), 113004.

Lasanta, T., Arnáez, J., Pascual, N., Ruiz-Flaño, P., Errea, M.P., Lana-Renault, N., 2016. Space–time process and drivers of land abandonment in Europe. Catena 149, 810–823. https://doi.org/10.1016/j.catena.2016.02.024.

Leal Filho, W., Mandel, M., Al-Amin, A.Q., Feher, A., Chiappetta Jabbour, C.J., 2017. An assessment of the causes and consequences of agricultural land abandonment in Europe. Int. J. Sustain. Dev. World Ecol. 24, 554–560. https://doi.org/10.1080/13504509.2016.1240113.

Leclère, D., Havlík, P., Fuss, S., Schmid, E., Mosnier, A., Walsh, B., Valin, H., Herrero, M., Khabarov, N., Obersteiner, M., 2014. Climate change induced transformations of agricultural systems: Insights from a global model. Environ. Res. Lett. 9 (12), 124018.

Lee, H., Brown, C., Seo, B., Holman, I., Audsley, E., Cojocaru, G., Rounsevell, M., 2019. Implementing land-based mitigation to achieve the Paris Agreement in Europe requires food system transformation. Environ. Res. Lett. 14 (10), 104009.

Levers, C., Müller, D., Erb, K., Haberl, H., Jepsen, M.R., Metzger, M.J., Meyfroidt, P., Plieninger, T., Plutzar, C., Stürck, J., Verburg, P.H., Verkerk, P.J., Kuemmerle, T., 2018a. Archetypical patterns and trajectories of land systems in Europe. Reg. Environ. Chang. 18, 715–732. https://doi.org/10.1007/s10113-015-0907-x.

Levers, C., Schneider, M., Prishchepov, A.V., Estel, S., Kuemmerle, T., 2018b. Spatial variation in determinants of agricultural land abandonment in Europe. Sci. Total Environ. 644, 95–111. https://doi.org/10.1016/j.scitotenv.2018.06.326.

Lieskovský, J., Bürgi, M., 2018. Persistence in cultural landscapes: a pan-European analysis. Reg. Environ. Chang. 18, 175–187. https://doi.org/10.1007/s10113-017-1192-7.

Maggi, F., Tang, F.H.M., la Cecilia, D., McBratney, A., 2019. PEST-CHEMGRIDS, global gridded maps of the top 20 crop-specific pesticide application rates from 2015 to 2025. Sci. data 6, 170. https://doi.org/10.1038/s41597-019-0169-4.

Malek, Ž., Tieskens, K.F., Verburg, P.H., 2019. Explaining the global spatial distribution of organic crop producers. Agric. Syst. 176, 102680.

McGreevy, S.R., Kobayashi, M., Tanaka, K., 2019. Agrarian pathways for the next generation of Japanese farmers. Can. J. Dev. Stud. 40, 272–290. https://doi.org/10.1080/02255189.2018.1517642.

McMichael, P., 2012. Food regime crisis and revaluing the agrarian question. Res. Rural Sociol. Dev. 18, 99–122. https://doi.org/10.1108/S1057-1922(2012)0000018007.

Mitter, H., Techen, A.-K., Sinabell, F., Helming, K., Schmid, E., Bodirsky, B., Holman, I., Kok, K., Lehtonen, H., Leip, A., Le Mouël, C., Mathijs, E., Mehdi, B., Mittenzwei, K., Mora, O., Øistad, K., Øygarden, L., Priess, J., Reidsma, P., Schaldach, R., Schoenhart, M., 2020. Shared Socio-economic Pathways for European agriculture: the Eur-Agri-SSPs. Glob. Environ. Chang. 65, 102159 https://doi.org/10.1016/j.gloenvcha.2020.102159.

Müller, D., Sun, Z., Vongvisouk, T., Pflugmacher, D., Xu, J., Mertz, O., 2014. Regime shifts limit the predictability of land-system change. Glob. Environ. Chang. 28, 75–83. https://doi.org/10.1016/j.gloenvcha.2014.06.003.

Nicholas, K.A., Villemoes, F., Lehsten, E., Brady, M. V., Scown, M.W., 2015. A harmonized and spatially-explicit dataset for the European Union's €61 billion in Common Agricultural Policy payments to farmers for 2015 1–8.

OECD, 2019. OECD regional outlook 2019 : leveraging megatrends for cities and rural areas. doi: 10.1787/9789264312838-en.

OECD, 2016. How stringent are environmental policies?.

Oldekop, J.A., Rasmussen, L.V., Agrawal, A., Bebbington, A.J., Meyfroidt, P., Bengston, D.N., Blackman, A., Brooks, S., Davidson-Hunt, I., Davies, P., Dinsi, S.C., Fontana, L.B., Gumucio, T., Kumar, C., Kumar, K., Moran, D., Mwampamba, T.H., Nasi, R., Nilsson, M., Pinedo-Vasquez, M.A., Rhemtulla, J.M., Sutherland, W.J., Watkins, C., Wilson, S.J., 2020. Forest-linked livelihoods in a globalized world. Nat. Plants 6 (12), 1400–1407.

Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvåg, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., Micale, F., 2011. Impacts and adaptation of European crop production systems to climate change. Eur. J. Agron. 34, 96–112. https://doi.org/10.1016/j.eja.2010.11.003.

Oliver, T.H., Boyd, E., Balcombe, K., Benton, T.G., Bullock, J.M., Donovan, D., Feola, G., Heard, M., Mace, G.M., Mortimer, S.R., Nunes, R.J., Pywell, R.F., Zaum, D., 2018. Overcoming undesirable resilience in the global food system. Glob. Sustain. 1, 1–9. https://doi.org/10.1017/sus.2018.9.

Oltermann, P., Jones, S., Rankin, J., Duncan, P., 2020. Germany and Spain scramble to reverse the flight of youth. Guard.

Otsuka, K., Nakano, Y., Takahashi, K., 2016. Contract farming in developed and developing countries. Annu. Rev. Resour. Econ. 8, 353–376. https://doi.org/10.1146/annurev-resource-100815-095459.

PwC, 2021. Megatrends [WWW Document]. Megatrends. URL https://www.pwc.nl/en/topics/megatrends.html.

Rivera, M., Guarín, A., Pinto-Correia, T., Almaas, H., Mur, L.A., Burns, V., Czekaj, M., Ellis, R., Galli, F., Grivins, M., Hernández, P., Karanikolas, P., Prosperi, P., Sánchez Zamora, P., 2020. Assessing the role of small farms in regional food systems in Europe: evidence from a comparative study. Glob. Food Sec. 26, 100417.

Robinson, G.M., 2018. Globalization of agriculture. Annu. Rev. Resour. Econ. 10, 133–160. https://doi.org/10.1146/annurev-resource-100517-023303.

Rotz, S., Gravely, E., Mosby, I., Duncan, E., Finnis, E., Horgan, M., LeBlanc, J., Martin, R., Neufeld, H.T., Nixon, A., Pant, L., Shalla, V., Fraser, E., 2019. Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities. J. Rural Stud. 68, 112–122. https://doi.org/10.1016/j.jrurstud.2019.01.023.

Scherer, L.A., Verburg, P.H., Schulp, C.J.E., 2018. Opportunities for sustainable intensification in European agriculture. Glob. Environ. Chang. 48, 43–55. https://doi.org/10.1016/j.gloenvcha.2017.11.009.

Schulp, C.J.E., Levers, C., Kuemmerle, T., Tieskens, K.F., Verburg, P.H., 2019. Mapping and modelling past and future land use change in Europe's cultural landscapes. Land use policy 80, 332–344. https://doi.org/10.1016/j.landusepol.2018.04.030.

Spinoni, J., Vogt, J.V., Naumann, G., Barbosa, P., Dosio, A., 2018. Will drought events become more frequent and severe in Europe? Int. J. Climatol. 38, 1718–1736. https://doi.org/10.1002/joc.5291.

SSB, 2021. STATBANK [WWW Document]. URL https://www.ssb.no/en/statbank.

Stahl, K., Kohn, I., Blauhut, V., Urquijo, J., De Stefano, L., Acácio, V., Dias, S., Stagge, J.H., Tallaksen, L.M., Kampragou, E., Van Loon, A.F., Barker, L.J., Melsen, L.A., Bifulco, C., Musolino, D., De Carli, A., Massarutto, A., Assimacopoulos, D., Van Lanen, H.A.J., 2016. Impacts of European drought events: Insights from an international database of text-based reports. Nat. Hazards Earth Syst. Sci. 16, 801–819. https://doi.org/10.5194/nhess-16-801-2016.

Stürck, J., Levers, C., van der Zanden, E.H., Schulp, C.J.E., Verkerk, P.J., Kuemmerle, T., Helming, J., Lotze-Campen, H., Tabeau, A., Popp, A., Schrammeijer, E., Verburg, P.H., 2018. Simulating and delineating future land change trajectories across Europe. Reg. Environ. Chang. 18, 733–749. https://doi.org/10.1007/s10113-015-0876-0.

Terres, J.M., Scacchiafichi, L.N., Wania, A., Ambar, M., Anguiano, E., Buckwell, A., Coppola, A., Gocht, A., Källström, H.N., Pointereau, P., Strijker, D., Visek, L., Vranken, L., Zobena, A., 2015. Farmland abandonment in Europe: Identification of drivers and indicators, and development of a composite indicator of risk. Land use policy 49, 20–34. https://doi.org/10.1016/j.landusepol.2015.06.009.

Van Boeckel, T.P., Glennon, E.E., Chen, D., Gilbert, M., Robinson, T.P., Grenfell, B.T., Levin, S.A., Bonhoeffer, S., Laxminarayan, R., 2017. Reducing antimicrobial use in food animals. Science (80-.). 357, 1350–1352. https://doi.org/10.1126/science.aao1495.

van der Ploeg, J.D., 2020. Farmers' upheaval, climate crisis and populism. J. Peasant Stud. 47, 589–605. https://doi.org/10.1080/03066150.2020.1725490.

van der Ploeg, J.D., Franco, J.C., Borras, S.M., 2015. Land concentration and land grabbing in Europe: a preliminary analysis. Can. J. Dev. Stud. / Rev. Can. d'études du développement 36 (2), 147–162.

van der Sluis, T., Pedroli, B., Kristensen, S.B.P., Lavinia Cosor, G., Pavlis, E., 2016. Changing land use intensity in Europe – recent processes in selected case studies. Land Use Policy 57, 777–785. https://doi.org/10.1016/j.landusepol.2014.12.005.

van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H., 2015. Manifestations and underlying drivers of agricultural land use change in Europe. Landsc. Urban Plan. 133, 24–36. https://doi.org/10.1016/j.landurbplan.2014.09.001.

Van Zanten, B.T., Verburg, P.H., Espinosa, M., Gomez-Y-Paloma, S., Galimberti, G., Kantelhardt, J., Kapfer, M., Lefebvre, M., Manrique, R., Piorr, A., Raggi, M., Schaller, L., Targetti, S., Zasada, I., Viaggi, D., 2014. European agricultural landscapes, common agricultural policy and ecosystem services: a review. Agron. Sustain. Dev. 34, 309–325. https://doi.org/10.1007/s13593-013-0183-4.

Vermeulen, S.J., Dinesh, D., Howden, S.M., Cramer, L., Thornton, P.K., 2018. Transformation in practice: a review of empirical cases of transformational adaptation in agriculture under climate change. Front. Sustain. Food Syst. 2 https://doi.org/10.3389/fsufs.2018.00065.

Ward, N., Jackson, P., Russell, P., Wilkinson, K., 2008. Productivism, post-productivism and European agricultural reform: the case of sugar. Sociol. Ruralis 48, 118–132. https://doi.org/10.1111/j.1467-9523.2008.00455.x.

WEF, 2021. The Global Risks Report 2021: 16th Edition, Global Risk Report.

Wens, M., Johnson, J.M., Zagaria, C., Veldkamp, T.I.E., 2019. Integrating human behavior dynamics into drought risk assessment—a sociohydrologic, agent-based approach. Wiley Interdiscip. Rev. Water e1345. https://doi.org/10.1002/wat2.1345.

Wilson, G.A., Burton, R.J.F., 2015. "Neo-productivist" agriculture: Spatio-temporal versus structuralist perspectives. J. Rural Stud. 38, 52–64. https://doi.org/10.1016/j.jrurstud.2015.02.003.

Zagata, L., Sutherland, L.A., 2015. Deconstructing the "young farmer problem in Europe": towards a research agenda. J. Rural Stud. 38, 39–51. https://doi.org/10.1016/j.jrurstud.2015.01.003.

Zimmerer, K.S., Jim, Y., Ruiz-ruiz, A., Porcel-rodr, L., 2020. Agri-food land transformations and immigrant farm workers in peri-urban areas of Spain and the Mediterranean. Land 9, 1–19.