Regenerating Europe *from the Ground Up*

EARA EUROPEAN ALLIANCE FOR REGENERATIVE AGRICULTURE

Farmer-led Research on Europe’s Full Productivity

The Realities of Producing More and Better with Less - Place-based Innovation for the Good of All

Full Report | Research Phase 1 | June 2025 | Version 1.2

This report marks the beginning of EARA's ongoing farmer-led research program, which breaks new ground both methodologically and empirically. At its core is a simple yet powerful idea: to measure what Europe's most pioneering farmers are achieving, across both agricultural and ecological dimensions, using a novel, farmer-centred index called Regenerating Full Productivity (RFP). Designed to be both comprehensive and easy to use, the RFP index offers a new way to understand and track the real-world productivity of agriculture. This first phase of research tests the index in practice, grounding it in the lived success of farmers already leading the transition.

About
The European Alliance for Regenerative Agriculture (EARA) is an independent, farmer-led coordination, advocacy and collective action organisation of the movement of regenerative agriculture at the European level. EARA is striving to enable the transformation of our agrifood ecosystems through accountable ecologic, economic and social regeneration.

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Disclaimer
The work underpinning this Report was commissioned and stewarded by the Farmers of the European Alliance for Regenerative Agriculture in order to bring the voices of regeneration practitioners and pioneers into the heart of the economic, agronomic and political discourses on the transformation of Europe's and the world's agrifood ecosystems.

The work was executed by a group of dedicated researchers made up of scientists, scientist-farmers, agronomists and economists, together with the technological services of AgriCircle's farm data intelligence experts.

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Our deep gratitude and hope lie with the great evolving, adaptive and resilient land steward movement around the world that already has a reflexive focus and has invested its efforts in the regeneration of the health of ecosystems and rural communities - the fundamental conditions of the health of our planet and all its inhabitants.

Study Participants, Advisors and Enablers

Executive Summary

Conventional agricultural models are not fit for purpose in the face of Europe's compounding crises in soil health, biodiversity, food system resilience, and climate stability. These challenges cannot be solved by current input-intensive farming systems designed for short-term yields. Such models now expose Europe to critical strategic vulnerabilities: reliance on imported food, feed and inputs, untenable rural livelihoods and fragile production systems increasingly disrupted by climate extremes. In response to this, EARA, together with cross-sectoral experts and institutions, conducted a multi-year pilot program covering 14 countries to demonstrate whether pioneering regenerative farmers can outperform conventional models, whilst improving ecosystems.

To facilitate this, the study introduces the Regenerating Full Productivity Index: a multidimensional performance metric developed by farmers, researchers and agronomists to capture the full spectrum of land stewardship outcomes: agronomic, ecological and economic. RFP builds on the conventional Total Factor Productivity (TFP) model, integrating field-level measurements, farmer-generated data, and satellite imagery, benchmarked at local, national and European levels. Unlike conventional metrics, RFP measures eco-effectiveness, synergies and context-specific outcomes.

Core Findings (Study period of 2021–2023)

→ **Higher full productivity:** Across all sites, regenerating farmers delivered 33% higher RFP on average, with gains ranging from 13% to 52%.

→ **Agroecological advantage:** Compared to neighbouring fields, regenerating farms achieved over 25% higher photosynthesis, 24% higher soil cover and 16% higher plant diversity from the period between 2019–2024. This advantage means more biodiversity and better soil health.

→ **Yield parity with major gross margin and input improvement:** Regenerating farms achieved, on average, only a 2% lower yield (in kilocalories and protein), while using 61% less synthetic nitrogen fertiliser and 75% less pesticides and making 20% higher gross margin per hectar.

→ **Regional food sovereignty:** While average EU farms import over 30% of livestock feed from outside the EU, pioneering farmers achieved similar yields using feed exclusively from within Europe.

These outcomes refute the assumption that Europe's food security depends on chemical-intensive agriculture. Instead, they affirm that regenerating systems, whether rooted in agroecology, conservation agriculture, organic farming, syntropic agroforestry or other disciplines, are not only viable but already superior in most contexts. Moreover, the progressive reduction, and eventual elimination, of synthetic inputs is not only feasible but also economically and environmentally beneficial.

Systemic Impact: From Resilience to Renewal
A 75% adoption of regenerating forms of agriculture could more than offset current EU agricultural emissions. If scaled EU-wide, the study estimates RFP-informed transitions could mitigate an estimated 513 Mt CO_2e/year, over 1.3x of the current EU agriculture sector emissions. By transitioning, the sector would become nature positive and climate resilient, ensuring food and fibre security while reversing ecological degradation and improving food quality and public health.

By enhancing soil health, water retention and biodiversity, regenerative systems reduce the frequency and severity of climate-induced shocks such as droughts, floods and crop failures. Investing in this resilience is cost-effective. According to the Boston Consulting Group (2025), investing 1%–2% of GDP in climate resilience could avoid losses worth 11%–27% of global output by 2100.[1]

1 Boston Consulting Group (BCG). (2025). Landing the economic case for climate action with decision makers. Boston Consulting Group. (LINK)

With only 6.5% of EU farmers under the age of 35 (as of 2020) the future of Europe's food systems is at risk.[2] Regenerative agriculture is also a social opportunity, offering a pathway to meaningful, ecologically-grounded work, especially for youth and women. Research demonstrates that many new entrants, particularly females, are drawn to farming as a meaningful and innovative profession, *when aligned with ecological and social values.*[3] About 40% of EARA's farmer members are women, well above the sector average, demonstrating the regenerative transition's potential to revitalise rural economies through skills, entrepreneurship and innovation.

Finally, regenerating forms of agriculture enhance Europe's competitiveness and strategic and economic resilience. By reducing dependency on external inputs such as fertilisers, pesticides, feed and fossil fuels, regenerating production systems lower the EU's exposure to supply chain disruption and geopolitical instability. A European Union that leads in supporting regenerative farming will be a global benchmark-setter, in the race to build a climate-ready, innovation-driven bioeconomy.

Policy Implications and Public-Private Pathways
This first phase of research demonstrates that RFP can serve as a foundational KPI framework to guide results-based policy reform, particularly in the context of the CAP and the EU's climate adaptation and security strategies. RFP can enable a harmonised Monitoring, Reporting and Verification (MRV) structure for a blended public-private transition finance system.This includes:

- A blended finance transition insurance scheme to derisk regenerative transitions;
- RFP-based eligibility for CAP payments, climate subsidies (such as ecosystem service payments) and private investment;
- Simplification of multiple regulatory and support frameworks without weakening critical environmental rules via a shared, result-based performance metric.

Next steps and Research Outlook
This pilot study encompassed 78 regenerating farms across 14 EU countries, covering over 7,000 hectares. It was conducted by 11 researchers with international institutional support, under the leadership of EARA's pioneering farmers. In phase 2, we will expand the evidence base through higher resolution satellite and fuel use data, broader farmer participation and the inclusion of new metrics. Despite budgetary constraints, this pilot marks a paradigm shift in agricultural performance measurement and ground-proofing, rooted in living system complexity and farmer reality.

2 Eurostat (2024, February 6th). Farmers and the agricultural labour force – statistics. Eurostat. Statistics explained. (LINK)
3 IP-AGRI Focus Group. (2016). New entrants into farming: Lessons to foster innovation and entrepreneurship. European Commission. (LINK)

A Call to Action

Europe's agri-food system stands at a crossroads. Continuing business-as-usual will deepen dependency, degrade ecosystems, increase climate risks and impose mounting costs.

Already, the European Commission estimates that agricultural revenue losses could reach €60 billion by 2025, rising to €90+ by 2050.[4]

This study shows that another way is possible, and already happening. Regenerating forms of agriculture, grounded in the RFP framework, offer a high-impact, accountable strategy to secure our food and planetary future. The tools are here, and the time to scale them is now.

4 Ficompass (2025) Insurance and Risk Management Tools for Agriculture in the EU. (LINK)

Figure List

Table list

Glossary

ALA	Omega-3 Fatty Acids
AUC	Area Under the Curve
CAFO	Concentrated Animal Feeding Operations
CAP	Common Agricultural Policy
CAPEX	Capital Expenditure
CSDD	Corporate Sustainability Due Diligence
CSRD	Corporate Social Responsibility Directive
EESC	European Economic and Social Committee
ETP	Evapotranspiration Potential
EUDR	EU Deforestation Regulation
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMO	Genetically Modified Organism
GPP	Gross Primary Production
GVA	Gross Value Added
HANPP	Human Appropriated Net Primary Production
LA	Omega-6 Fatty Acids
LAI	Leaf Area Index
LCA	Life Cycle Analysis
LULUCF	Land Use, Land Use Change and Forestry
MRV	Monitoring, Reporting, Validating
MUFA	Monounsaturated Fats
NCD	Non-Communicable Disease
NDVI	Normalized Difference Vegetation Index (NDVI) for vegetation health monitoring
NPP	Net Primary Productivity
PES	Payments for Ecological Services
PLI	Pesticide Load Indicator
ROI	Return on Investment
RFP	Regenerating Full Productivity
RMSE	Root Mean Square Error
SAS	Syntropic Agroforestry Systems
SFS	Silvopastoral Farming Systems
SGM	Standard Gross Margin
SMRL	Sustainable Management of Natural Resources and Land
SMW	Statistical Mono-Window
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TFP	Total Factor Productivity
TYFA	Ten Years For Agroecology study
UAA	Utilised Agricultural Area
WUE	Water Use Efficiency
WFRD	Wild Forest and Restoration

EARA

„This study is a call to realize the following: restoring ecosystems while being productive and profitable is not a dream of some theory-lovers sitting in offices: it is what pioneer farmers are achieving on their fields throughout Europe. Let‘s support the dissemination of their techniques, for our common good.“

Dr. Yann Boulestreau, EARA Farmer, Scientist,
Co-Founder AgSynergie and member of research team of this study

1 Introduction

1 Introduction

This study presents the first-high resolution, systematic, empirical benchmarking of pioneering regenerating farmers across the EU, revealing that they consistently outperform average conventional peers in ecosystem services, biodiversity and input efficiency between 2021 and 2023. Using the new Regenerating Full Productivity (RFP)[5] index, this research confirms that regenerative land use systems are not only ecologically superior but also more productive, resilient and economically viable, offering a practical basis for results-based funding and policy coherence.[6]

This research project and its first phase study, conducted by EARA in collaboration with cross-sectoral partners and experts, analysed the productivity of Europe's pioneering agricultural land use stewards (farmers) who practiced regenerating forms of agriculture from 2021 to 2023. The study introduces and tests the Regenerating Full Productivity (RFP) index, a comprehensive, multidimensional performance framework developed to assess the full productivity of land management practices by integrating ecological, agronomic and economic outcomes.

Through a robust benchmarking methodology across crop/field, national and European scales, and using both farmer-generated and remote sensing data, this study tests the hypothesis that pioneering regenerating farmers can match or outperform average conventional counterparts; not only in yield, resilience and climate performance, but also in the regeneration of soils, ecosystems and biodiversity. In doing so, it aims to fill a critical evidence gap left by conventional productivity models and methodologies, which often undervalue the eco-effectiveness, synergies and long-term health outcomes of regenerative approaches.

All of Earth's primary resources - water, food, fibre, fuel, minerals, chemicals - are inherently linked to the land use sector. Downstream, the land use sector underpins the vitality of all economies dependent on these primary resources for value addition, including pharmaceuticals, textiles and energy. Despite its key role in the global economy, the land use sector is simultaneously the most threatened[7] by, and a leading driver of, climate breakdown, desiccation, mass biodiversity extinction and negative demographic trends.[8] The past decade has seen the decline in productivity and vigor of Europe's land use sector[9]. This loss in biomaterial productivity resilience[10] is the single greatest threat to European autonomy, sovereignty, security, prosperity and health. It is imperative to understand that European societies and economies fundamentally depend on a thriving, constantly improving - and thus regenerating - land use sector.

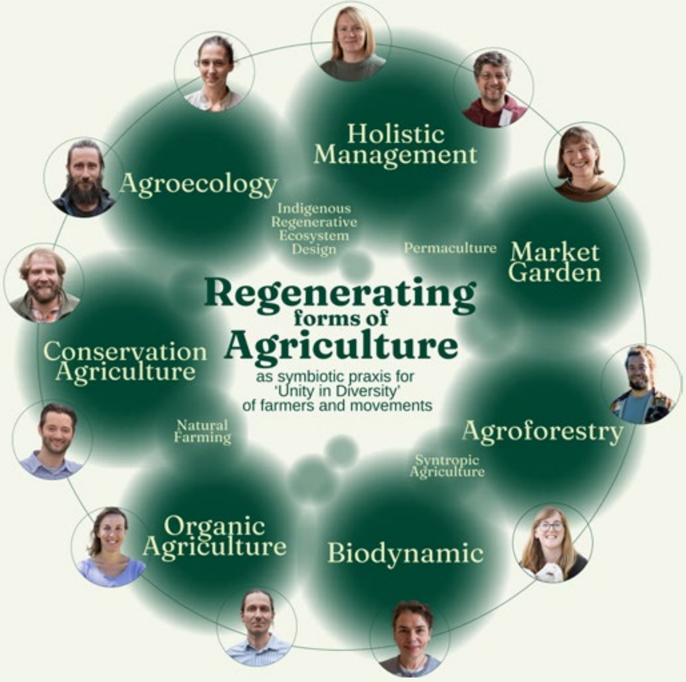

Figure 1: Overview of regenerating forms of agriculture

Unlike other studies assessing land use sectors that base their conclusions on modelling with coefficients from existing databases and literature, the underlying data for this study has been empirically collected, measured and benchmarked in context-specific environments. The productivity of these pioneers is benchmarked to the average farmer productivity of the same respective crop (including livestock), region and year, out of a national crop basket and an overall crop basket of the European Union over the years 2021 - 2023. Our approach provides a stronger insight because of being able to account trade-off and synergy effects, while measuring in high resolution.

5 EARA chose the term regenerating full productivity (RFP) rather than total factor productivity (TFP) (discussed below) to emphasize its broader and more integrative scope. Etymologically, „full" conveys completeness and filling towards abundance (from roman and germanic roots), reflecting an approach that accounts not only for direct inputs and outputs, but also for second-order effects, unintended consequences, and externalities. Full productivity sets a trajectory not toward scarcity, but toward abundance, where syntropy, not entropy, defines developmental progress by enriching soils, ecosystems, and communities with ever more regenerating and productive life.
6 EARA uses the term 'regenerating forms of agriculture' instead of 'regenerative agriculture' on the basis that regeneration is a continuous process rather than a singular one and that regeneration is 'unity in diversity' facilitated by cooperation of actors from different backgrounds.
7 The Guardian, Land degradation expanding by 1m sq km per year. (LINK)

8 Hanewinkel et al., (2013). Climate change may cause severe loss in the economic value of European forest land. Nature climate change, 3(3), 203-207.(LINK)
9 European Environment Agency.
Impact of land use on vegetation productivity in Europe (LINK)
10 Schmidt, M., & Felsche, E. (2023). The effect of climate change on crop yield anomaly in Europe. Climate Resilience and Sustainability, 3(1) (LINK)

This pilot programme therefore draws together a variety of epistemological, methodological, data and technological innovations that are put into action by the independent leading farmer organization EARA, alongside many other leading farmer organizations, businesses, scientists and experts.

This study shows that the pioneering farmers practicing regenerating forms of agriculture can and do produce relatively only 2% less yields, similar incomes, far over 25% more ecosystem services and biodiversity, using 61% less synthetic nitrogen fertilizer, 75% less pesticides and 92% less non-national feed than their averaged context-specific peers.

The study combines these productivity factor indicators[11] into a novel, public interest-guided, multidimensional productivity index that EARA terms Regenerating Full Productivity (RFP). According to the RFP index, the pioneers have 33% higher Regenerating Full Productivity than average European farmers. The study further shows how strategic result-based remote-sensed indicators[12] show a consistent influence on RFP of 41% and thus can serve as the anchor for public and private performance-based payments for food security, farm income, soil, plant, animal and human health, as well as ecosystem service provisioning.

11 Traditionally, we frame human land use as an inherent trade-off with ecosystem health, assuming that the human appropriation of net primary production (HANPP) necessarily reduces ecosystem vitality. However, updated scientific understanding shows that advanced forms of regenerative agriculture can outperform the NPP of unmanaged ecosystems. In addition to minimizing harm, regenerative practices actively restore and enhance ecosystem functions: they rebuild soil carbon, improve water cycles and increase biodiversity, thereby raising the "life-holding capacity" of both land and community. More information is provided in our (Policy Paper)
12 The remote-sensed indicators are pedoclimatic context-specific, analysing whole-year photosynthesis and soil cover.

1.1 Context: Europe's degrading land use sector, bioeconomy and rising food insecurity

Degrading economic, ecological and social trends of Europe's land use sector and bioeconomy are well documented within the context of Europe's bioeconomy. In their recent CAP opinion, the EESC highlights the desperate situation, emphasising the impact of interrelated challenges:

- Economic hardship: inflation together with unpredictable energy markets that disrupt the fair living standards of EU farmers[13], with farmers' income at around 40% lower than non-agricultural income[14].
- Diminishing total farm numbers in the EU (9.1 million farms in the EU in 2020, 25% fewer than in 2010). These shifting dynamics have seen an outflow of labour from agriculture (a 23% drop in annual work units in 10 years, with 22 million people now working regularly in the sector)[15].

Livestock farms are disproportionately affected by this demographic stress, with total livestock farms having decreased by 40% in the decade from 2010, 35% greater than the drop for farms without animals[17]. The average farm size increased from 13.2 ha to 17.4 ha over this same period, a reflection of present conditions that lead to land ownership becoming ever more concentrated in fewer and corporate hands, while small, family-owned businesses struggle to survive and many ultimately do not succeed.

The accumulation of these social and economic concerns is further slowing the generational renewal of European farms, as there is little to no incentive for young farmers to install themselves in rural areas. Figure 3 shows that only 6.5% of farmers are under 35, with more than 30% over 65. In congruence with age diversity, gender diversity is also misrepresented. Female farm managers account for a significantly smaller fraction of farm owners/managers compared to their male counterparts. The missing female and future farming generations are jeopardizing the future of European agriculture and society at large.

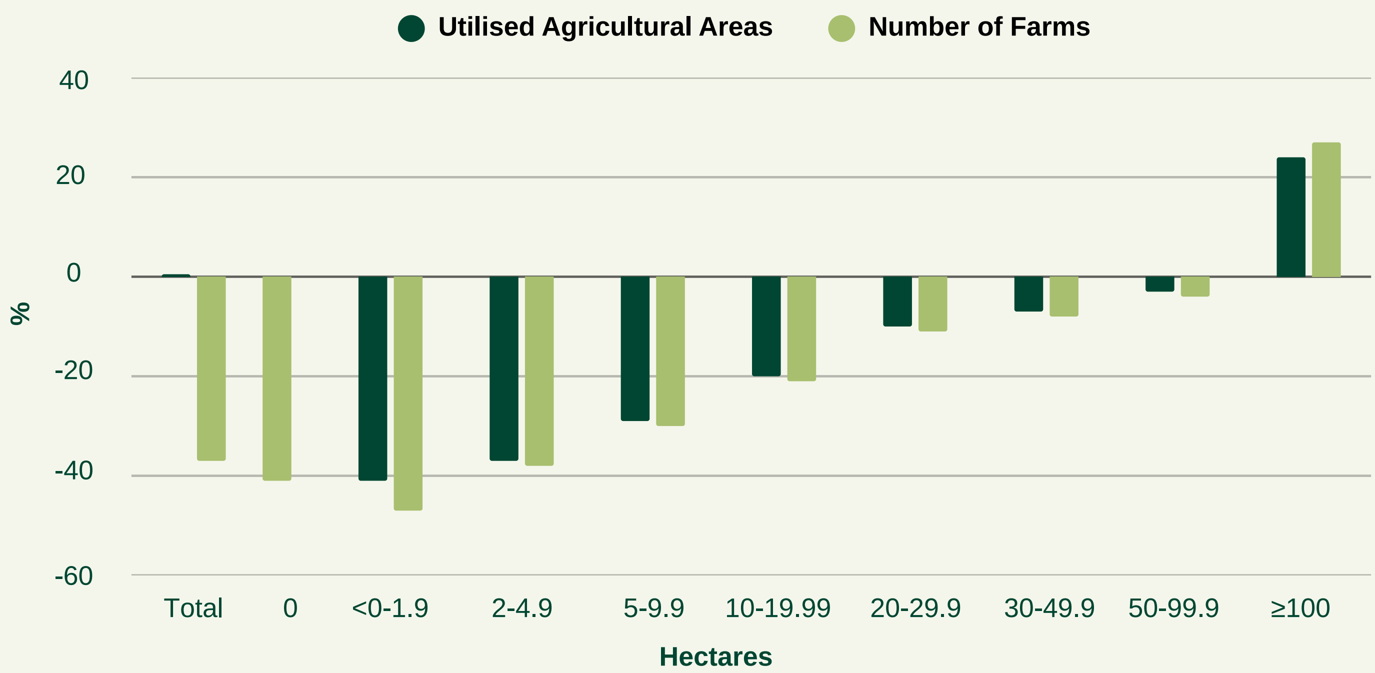

Figure 2: Shift in EU number of farms and utilised agricultural area from numerous small farms to fewer large farms during 2005-2020[16]

13 EESC opinion on The impact of high energy prices on the agricultural sector and rural areas (LINK) (not yet published in the Official Journal).
14 European Commission, The CAP at a glance (LINK).
15 A medium-term outlook on the prospects for agricultural markets and income (LINK). EU AGRICULTURAL OUTLOOK. FOR MARKETS, INCOME AND ENVIRONMENT 2022 - 2032 (LINK)
16 Eurostat. Farms and Farmland in the European Union: Statistics. (LINK)

17 World Economic Forum. EU Farm Statistics: 5.3 Million fewer in 2020 than in 2005. (LINK) Agriland. European livestock farms decreased by 40% over a 10-year period. (LINK)

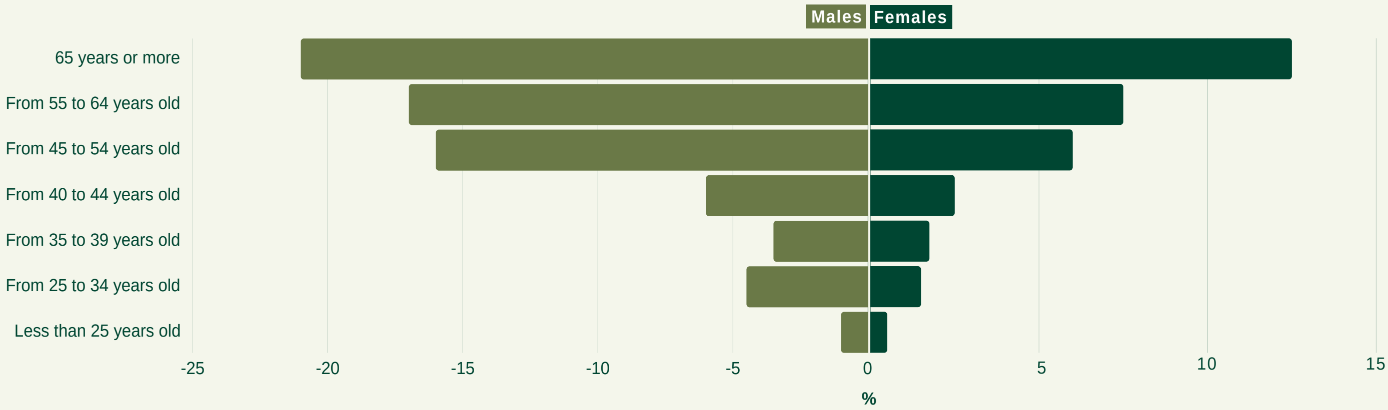

Figure 3: Age and gender distribution of European farm managers[18]

Compounding these economic and demographic constraints, farmers are faced with increasingly degraded soils and climate chaos, resulting in decreasing yields, and undermining the ecosystem productivity of European agriculture. Dramatic fluctuations in agricultural production are becoming more frequent.

- 2018: 40% of the cropped area in Northern and Eastern Europe experienced winter wheat and barley yields that ranked among the lowest 10% of historical observations of the last decades.[19]
- 2022: European agricultural production suffered due to the extreme drought of August 2022, with staple crop productions significantly decreasing, compared to the 5-year average. Specific losses included 16% for maize, 15% for soybean and 12% for sunflowers[20].
- 2023: Yields further deteriorated. The EU's overall maize production for 2023 was projected to be 10-15% lower than the 5-year average[21], with maize yields dropping 20-30% in Romania, 15-25% in Hungary and Bulgaria, and 10-15% in France, due to drought[22]. Stone fruit production also fell sharply, with 20-30% lower peach and nectarine yields in Spain and 15-25% declines in Italian apricots[23]. Vegetable yields suffered similarly, with tomatoes down 10-20% in Southern Europe and potatoes 5-10% lower in Northern Europe due to climatic conditions.
- 2024: continued to be difficult. The production of Europe's staple fruit, apples, reduced on average 11%, with Czechia experiencing up to 76% losses[24]. Cereal production also suffered, with losses estimated at approximately 7% below the 5-year average[25].

As yields decrease while consumption remains steady, the EU's biomaterial dependencies on imports are solidified. Today, the EU is a net importer of both calories and proteins, relying on foreign producers for 11% of the calories and 26% of the proteins it needs[26].

Climate chaos is shifting climate zones and intensifying weather extremes, with altered precipitation patterns causing both more extreme rainfall and also droughts. More unstable atmospheric dynamics are leading to unusual and extreme weather patterns which have negative consequences beyond the direct reduction of agricultural yields[27].

18 Eurostat. Farms and Farmland in the European Union: Statistics. (LINK)
19 Beillouin et al., (2020). Impact of extreme weather conditions on European crop production in 2018. Philosophical Transactions of the Royal Society B, 375(1810), 20190510. (LINK)
20 Schmidt, M., & Felsche, E. (2024). The effect of climate change on crop yield anomaly in Europe. Climate Resilience and Sustainability, 3(1), e61. (LINK)
21 Trompiz & Heinrich. (2023). EU raises 2023/24 maize harvest estimate. (LINK)
22 European Commission. (2023). Below-average maize yield expected in the EU. (LINK)
23 European Commission. (2023). Stone fruit: Market presentation 2023/24 – Summary (LINK)
24 European Commission. Apple production 2024 (LINK)
25 European Commission. (2024) Short-term outlook of agricultural markets: Gradual but fragile return to stability. (LINK)
26 Ruiz Mirazo. (2022). Europe Eats the World. WWF. (LINK)
27 García-García et al. (2023). Soil heat extremes can outpace air temperature extremes. (LINK)

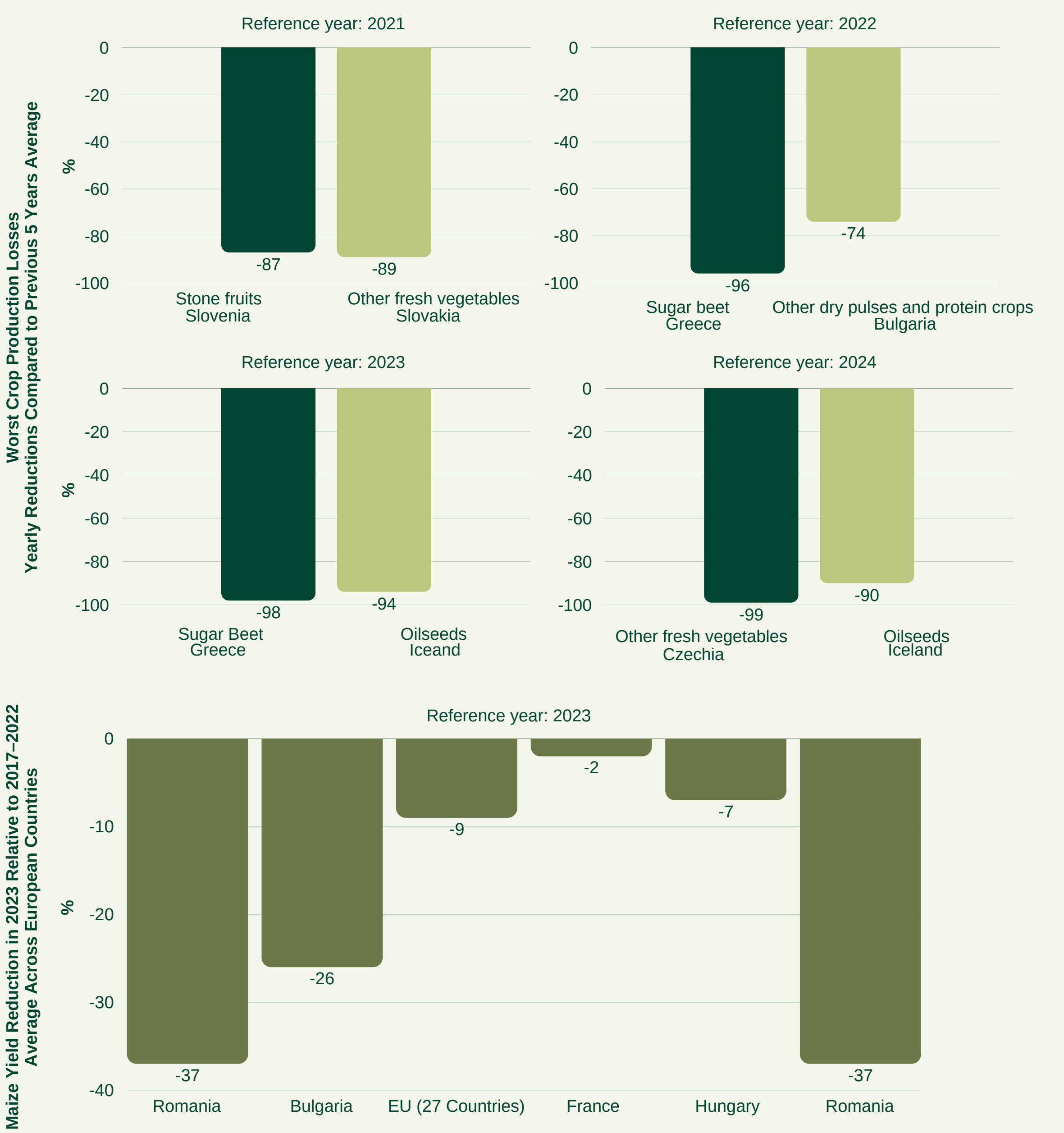

Figure 4: Overview of biggest yield declines in Europe 2021-2024[28]

Such impacts, compounded with downcycling effects of extensive use of agrochemicals, are leading to inefficient carbon cycling and sequestration, further degradation of soil health[29] and increased land use carbon emissions due to erosion and oxidation. Cumulatively, these effects drastically lower farm incomes and in the long-term can decrease land prices as well.

Further, disrupted small water cycles[30] and plummeting biodiversity are accelerating the crises of the land use sector, and impacting the wider European community[31]. These changes affect not just yields, but also result in damage and destruction in the form of wildfires, floods and landslides.

28 Data Source: Eurostat. (n.d.). Crops products: Harvested production by NUTS 2 regions (apro_cpsh1). (LINK)
29 Mandalet al. (2020). Impact of agrochemicals on soil health. In Agrochemicals detection, treatment and remediation (pp. 161-187). (LINK)

30 Small water cycles refer to the localised movement of water through evaporation, condensation and precipitation within a limited geographic area, such as a farm, forest or watershed. Unlike large-scale (global) water cycles, small water cycles are strongly influenced by land use and vegetation cover. Regenerative practices that improve soil structure and plant cover can restore these cycles, enhancing local rainfall patterns, soil moisture retention and climate resilience.
31 Curtis et al., (2018). Increase in crop losses to insect pests in a warming climate. Science 361,916-919 (LINK)

1.2 Objectives

This study seeks to address the challenges of Europe's degrading land use and bioeconomy context by highlighting the pathways that pioneering European farmers have developed toward growing resilient, healthy and productive agricultural systems. The results of these farmers will be examined to demonstrate how the outcome-based and farmer-led regeneration of diverse agroecosystems positively impacts the overall wellbeing of the EU.

The three primary objectives of this study are to:

1. Document the results that pioneer European farmers are making for food security and sovereignty, strategic autonomy[32], health and nature.

2. Demonstrate the difference between average farmers and Europe's pioneering farmers practicing regenerating forms of agriculture, using a systematic, innovative and future-oriented performance assessment index called Regenerating Full Productivity (RFP)[33].

3. Validate the robustness of remote-sensed indicators as efficient and meaningful proxy performance indicators in line with our Policy Proposal for a meaningful transformation of the Common Agricultural Policy (CAP), published in April 2024[34]. These indicators can be used to measure progress towards the efficient production of multiple public goods like soil, water, and biodiversity as well as food, fibre and farm income.

These objectives respond to the most pressing concerns in the context of the global and European agri-food sector and wider economies and societies. They integratively address the largest problems of our societies, land use sectors and bioeconomies[35].

32 The European Economic and Social Committee (EESC) defines „open strategic autonomy" as the EU's ability to act independently while engaging in global cooperation, applying this concept to food systems by reducing dependencies in critical sectors, strengthening food production and the agricultural workforce, promoting fair trade, and ultimately ensuring a fair, sustainable, and resilient food supply for all EU citizens.
33 We use the term „Regenerating Full Productivity" instead of „Total Factor Productivity" to reflect a more integrative approach that accounts for externalities and aims for abundance, enriching soils, ecosystems, and communities through syntropic growth.
34 EARA. Towards a farmer and agroecosystem health centred CAP. (LINK)
35 We define bioeconomy as an economy in which we recognize that 100% of value creation on earth depends in its first instance, even before labor, on Net Primary Productivity and hence steward our economies accordingly.

1.3 Review of related literature and methodologies

Many studies and methodologies recognize the same problems and identify similar objectives for their work. However, many of these studies rely on outdated data and scientific assumptions (e.g. of soil[36] and water science[37]) regarding the evolution of the EU agrifood system. These limitations have resulted in misleading assessments of both present conditions and future potential. The core methodological problems (epistemological, methodological and data-related) are summarised below and further elaborated in Appendix 2.

Epistemological Blind Spots:
Ignoring Eco-effectiveness and One Health
Most mainstream agricultural and environmental modelling frameworks prioritise eco-efficiency (maximising output per unit input) while neglecting eco-effectiveness (the capacity of systems to regenerate ecological functions). This bias has major implications for both scientific understanding and policy design. Similarly, the One Health[38] perspective, which recognises the interdependence of human, animal and environmental health, is often excluded from such conventional models.

These omissions create structural blind spots. For example, they contribute to overestimating the sustainability potential of industrial, input-intensive livestock systems such as Concentrated Animal Feeding Operations (CAFOs), and to underestimating the long-term systemic risks and externalities of novel highly-processed foods such as 'Alternative Proteins'.

Conventional models systematically undervalue low-input or regenerating farming systems, by failing to account for the long-term ecological and health co-benefits of synthetic input extensification and ecological intensification[39]. Conversely, practice-based interventions designed to intensify input-use may appear to overperform, despite their often unmeasured or misrepresented externalities and vulnerability to climate, biodiversity and supply shocks[40].

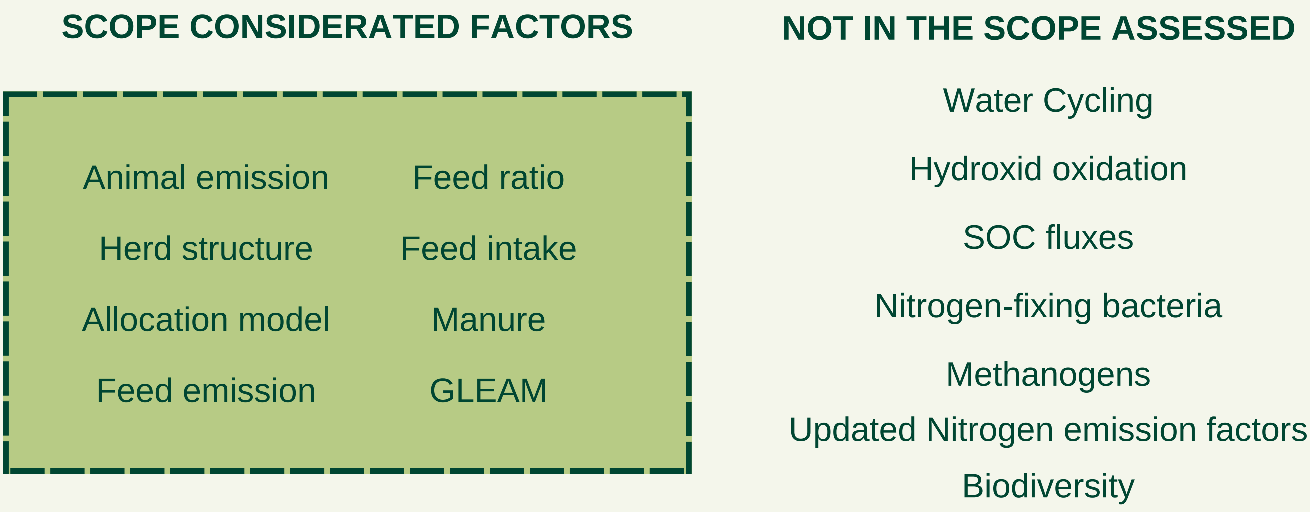

Figure 5: Scope limitations of life cycles assessments: FAO's global livestock environmental assessment methodology

36 NABU. (2023). Joint position paper on EU soil health law. (LINK)
37 UNEP. (2024) New Water Paradigm (LINK)
38 International Centre for Development of Agricultural Sustainability. (2023). Manifesto for One Health in Europe 2023. (LINK)

39 For a wider conceptual and literature discussion of the problems of the binary of intensification and extensification see our Policy Paper.
40 Wang et al., (2022). Agricultural eco-efficiency: Challenges and progress. (LINK)

Methodological Constraints: Context-Free and Monocausal Modelling
Many studies[41] use context-independent methodologies, relying on data from isolated trials or meta-analyses. These are then extrapolated into scenario models based on normative assumptions about future behaviour, such as the adoption of particular technologies or dietary shifts. This introduces several key limitations:

- Selection bias: Researchers only use data and results that align with dominant or mainstream assumptions.
- Lack of system interactions: Models frequently exclude antagonistic and synergistic effects that emerge only in real-world land-use systems.
- Simplistic causality: The ceteris paribus logic (holding all else equal) masks the complexity of farm decision-making and ecological feedback loops.

As a result, these models often fail to reflect the dynamic, multivariable performance of regenerative systems, which depend on complex interactions rather than isolated inputs or outputs.

Data Lag and Innovation Gaps
Many agricultural models rely on empirical data that lag significantly behind on-the-ground innovation[42]. This is particularly problematic when evaluating pioneering farmers, who often adopt synergistic methods that create benefits greater than the sum of their parts.

These synergistic approaches, involving multiple interdependent variables and designed to optimise whole-system functioning, are difficult to capture and often excluded by the ceteris paribus method. Conventional trial setups seek to isolate monocausal relationships between dependent and independent variables (eg. fertilizer X on yield of crop Y). While this method may be analytically neat, it misrepresents how actual farms function and evolve. Farmers manage complexity, not variables in isolation.

Fundamentally, research that privileges monocausal design is significantly removed from farmer reality, less suited to understanding real-world performance, and ultimately less capable of guiding transformative change.

41 Winsberg, E., Oreskes, N., & Lloyd, E. A. (2013). Philosophy of climate science. Synthese, 190(11), 2091–2105. (LINK); Wilkinson, A., Kupers, R., & Mangalagiu, D. (2015). How scenario planning influences strategic decisions. European Journal of Operational Research, 246(3), 849–864. (LINK);
Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: Towards a user's guide. Futures, 38(7), 723–739. (LINK)
42 For example: A farmer and/or a business develop an innovation, in order to enter the model usually a 3 year ceteris paribus field trial must be done. Naturally, the earliest an innovation could be taken up in a model is after 5-10 years.

Kellogg Biological Station
The long-term Main Cropping System Experiment at the Kellogg Biological Station in Michigan[43], established in 1988, investigated various cropping systems in a highly controlled format, with six replicate blocks, each containing seven 1-hectare plots. While this setup reduces internal bias within the trial design, its external validity is limited. It represents an artificial, static system that contrasts sharply with the adaptive, knowledge-intensive management of real farms.

The logic of only changing one variable over decades assumes that land users act as if they cannot learn or adapt; an unrealistic premise. Furthermore, living systems involve uncertainty, non-linearity, and multiple unobservable variables. The presumed causal relationship (eg. between no-tillage and yield[44]) may actually reflect unrelated, compounding and unmeasured variables, such as pathogenic infections or infestations.

Syntropic Agroforestry Meta-Review
In contrast, a recent systematic review of syntropic agroforestry (figure 6) showcases a more holistic and ecologically-grounded research paradigm. While many included studies suffer from self-selection bias, they nevertheless demonstrate how integrated, polycultural systems consistently outperform monocultures and even surpass natural regeneration in key performance metrics.

The systematic review demonstrates that synergies inherent in diversified systems lead to higher productivity, resilience and regeneration.

The practical limitations of models lie in their applicability and relevance to decision-making by policymakers, businesses, investors, civil society and farmers.
When financial, political or social decisions are based on models that do not adequately reflect real-world complexity, there is a risk that the resulting actions are shaped by incomplete or biased assumptions.

To demonstrate the limitations of these models, we will briefly examine several studies that look to shape the future of the European agricultural sector, with a more extensive analysis in Appendix 2. The studies' methodological shortcomings are emphasised with the aim of preparing the reader to understand the scientific innovations in agricultural, bioeconomic, climate and ecological sciences that EARA has designed, applied and now proposes for wider implementation.

43 Robertson, G. P., Gross, K. L., Hamilton, S. K., Landis, D. A., Schmidt, T. M., Snapp, S. S., & Swinton, S. M. (2014). Farming for ecosystem services: An ecological approach to production agriculture. BioScience, 64(5), 404–415. (LINK)
44 In the study, trial site 2 follows the Corn–soybean–wheat rotation as in trial site 1, but differs through no-tillage use, whereas site 1 is managed with standard chemical inputs and conventional tillage.

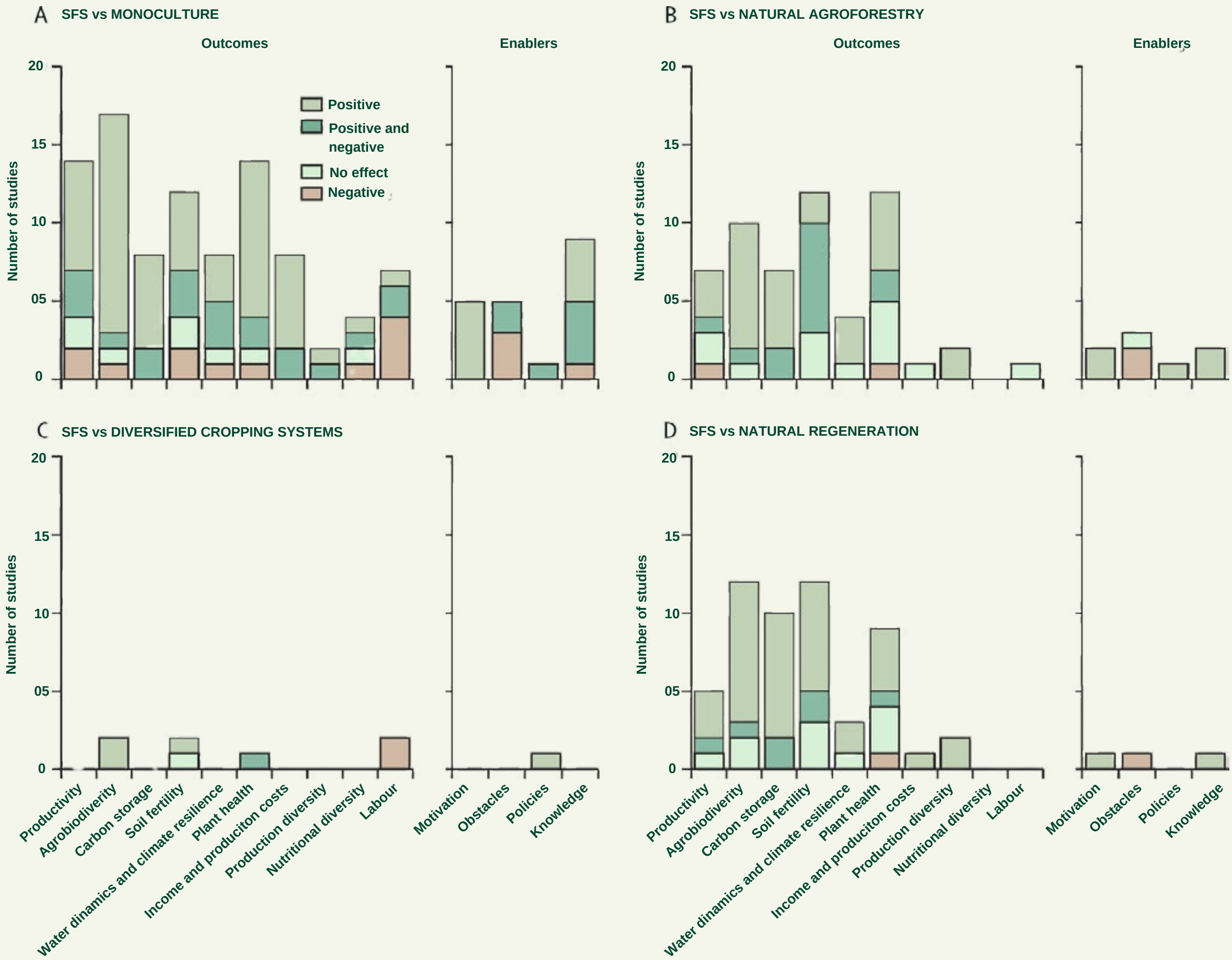

Figure 6: Systematic review comparing syntropic agroforestry systems (SFS) to other land uses [45]

45 Jacobi et al. (2025). Syntropic farming systems for reconciling productivity, ecosystem functions and restoration. The Lancet Planetary Health, 9(4), e314-e325 (LINK)

1.3.1 Other studies assessing the future of European agriculture and land use

Studies conducted by the Institute for Sustainable Development and International Relations (IDDRI), Agora Agrar, World Resources Institute (WRI) and Wageningen University & Research (WUR) illustrate the persistent epistemological and methodological reductionism within modern agricultural and environmental modelling frameworks. Despite varying in ambition and rigour, they exhibit assumptions about input-output relationships, and a preference for techno-optimistic narratives, that miss the potential of regenerating forms of agriculture. Each of the mentioned studies is discussed in more depth in Appendix 2.

IDDRI: An agroecological Europe by 2050
The study by IDDRI (An agroecological Europe by 2050: Findings from the Ten Years for Agroecology (TFYA) modelling exercise) represents the most scientifically robust and relevant contribution within the scope of this paper. It models the agroecological transition in Europe through reduced inputs and the recognition of the productive impact of ecosystem services, while accounting for trade. Still, the TYFA analysis cannot fully demonstrate the potential of agroecological innovation due to the assumption of significant yield losses. Accurate yield projections would need the methodological and data capacity to integrate the synergies associated with regenerating and agroecological land use management, which the authors note within the report. The study's findings are cautious, and do not account for the cumulative effects of redirected research and development towards agroecology, or the resilience gains from reducing environmental externalities. This study complements the TYFA study by demonstrating the positive synergistic effects of regenerating forms of agriculture on yields resulting from place-based biological intensification.

Agora Agrar: Agriculture, Forestry and Food
The broader benefits of regenerative agricultural systems demonstrated by SFS (Silvopastoral Farming Systems), have historically been underrepresented in mainstream agricultural science literature. A widely cited report from Agora Agrar, Agriculture, Forestry and Food in a Climate-Neutral EU, illustrates this tendency toward selection bias. While the study acknowledges the biodiversity benefits of agroforestry, it paradoxically promotes monoculture tree plantations on grasslands, while overlooking the well-documented advantages of agroecological practices such as silvopasture, cover and intercropping, strip- and no-till systems, and rotational grazing[46].

Consistent with the prevailing "intensification" paradigm, the report focuses on increasing carbon efficiency through livestock reduction and greater legume integration, yet it offers no targeted support for mixed or integrated farming systems. In doing so, it reduces livestock to a single variable, carbon emissions, neglecting their potential contributions to ecological regeneration and resilient land use systems.

Wageningen University & Research: EU Green Deal
Similarly, an impact assessment of the EU Green Deal targets by Wageningen University & Research demonstrates a strong methodological bias favouring high-input, high-output conventional systems. Through the ceteris paribus approach that assumes 'all things being equal', the models simulate the sudden removal of inputs and predict yield declines. However, such outcomes are not representative of real world transitions, where input reductions are typically accompanied by preparatory and complementary measures. Crucially, the study fails to model viable transition pathways that include strategies for biological intensification or regenerative approaches. Consequently, the findings reinforce a false narrative of inevitable yield loss, overlooking the adaptive capacities of farmers and the resilience of diversified systems. The following sections of this study challenge this assumption, drawing on empirical evidence and the growing impact of climate volatility on conventional production.

World Resources Institute: Pathway to Carbon Neutral
The World Resources Institute (WRI) study (A Pathway to Carbon Neutral Agriculture in Denmark) further demonstrates systematic oversights in both its methodology and epistemological approach. With a narrow focus on carbon efficiency, it proposes a carbon offset strategy based on speculative assumptions that yields in Brazil would double through the adoption of new GMO varieties which do not exist. The study fails to consider the consequences of such unproven technological interventions on biodiversity, soil degradation and rural communities. These theoretical yield increases would be accompanied by reforestation projects in the area spared from agriculture due to the intensification of production, allowing the sale of carbon credits to offset the remaining emissions of the Danish agricultural sector, with a doubled CAFO-managed, import-dependent pig production in 2045. These carbon credits would not reflect a real offset given the wider environmental harm of a doubled CAFO operation.

46 Monoculture tree plantations are inherently limiting of biodiversity, notably birds, insects and plant-life. Shown through Shiva, V. (1993). Monocultures of the mind: Perspectives on biodiversity and biotechnology. (LINK)

This section touches only the surface of the necessary and long overdue discussion on the philosophy, epistemology and methodology of the sciences of agricultural economics and all related disciplines. A more detailed discussion can be found in Appendix 2.

While the IDDRI study is limited only in its capacity to display the synergetic effects of bio-intensive regenerating forms of agriculture, the other studies have deep epistemological, methodological and data problems - despite having been extensively reviewed and commonly referenced. These issues do not only relate only to agricultural economics, but to the general understanding of the potential of agriculture and the land use sector.

1.3.2 Rethinking Total Factor Productivity in favour of Regenerating Full Productivity - Shortfalls of the standard approach for assessing agricultural performance over time and space

Alongside models that aim to assess the future of Europe's land use, widely used methodologies also assess past and present agricultural productivity. These approaches are central to this study, as they shape the understanding of current performance and influence strategic decisions across policy and investment, and ultimately influence farm management.

The Promise and Limits of Total Factor Productivity (TFP)
The most commonly used metric is TFP, which measures the efficiency with which inputs (labour, capital, land, agrochemicals, etc.) are converted into agricultural outputs. TFP is widely accepted as a key indicator of performance and is used for policy assessment at both national and international levels[48].

This study acknowledges the value of TFP's core aim: to provide a comprehensive productivity index applicable across micro and macroeconomic scales. We draw on its methodological foundations to develop a new framework called **Regenerating Full Productivity (RFP)**. This builds on and addresses the shortcomings of TFP. The development of RFP is a central objective of this research and is discussed in detail in the methodology section below.

Beyond reforms of the TFP
Recent years have seen some reflections within TFP literature on methodological limitations, particularly as productivity growth has stalled in mature agricultural economies. Institutions such as the OECD and others have proposed improvements to TFP models by incorporating environmental performance indicators and farm-level data[49]. These proposals aim to align productivity metrics more closely with sustainability goals by accounting for the costs and benefits of changes in environmental outcomes[50].

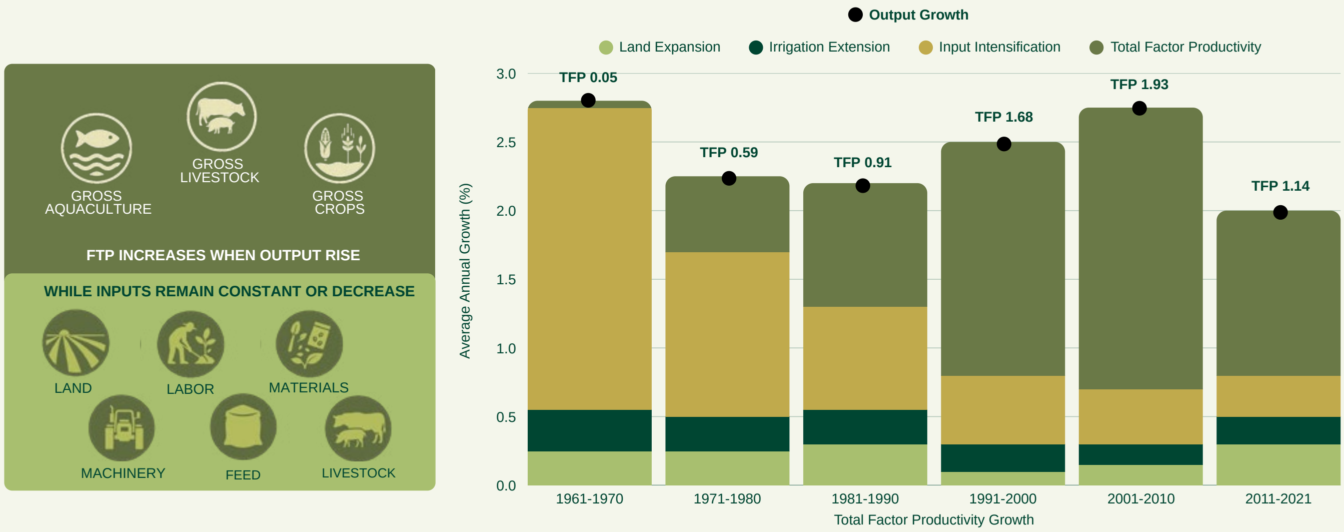

Figure 7: Scope and drivers of global total factor productivity (TFP) growth[47]

47 Thompson, T. (Ed.). (2023). Chapter One – Total Factor Productivity. In 2023 Global Agricultural Productivity Report: Every Farmer, Every Tool. Virginia Tech College of Agriculture and Life Sciences. (LINK)

48 OECD Network on Agricultural Total Factor Productivity and the Environment (LINK)
49 For example, a reduction in greenhouse gases emissions, if standard inputs and outputs are unchanged, should be reflected as an improvement in performance.
50 OECD (2022). Insights Into the Measurement of Agricultural Total Factor Productivity and the Environment (LINK)

While such reforms are a step in the right direction, they remain insufficient to address the scale and nature of the ecological and social crises facing Europe's agricultural systems. These efforts tend to focus on marginal improvements in eco-efficiency, namely in producing the same output with fewer negative impacts. Stagnating or decreasing yields with higher input usage demonstrates that the agricultural sector is approaching the limit of this approach[51]. What is needed is a re-imagining of the system to generate eco-effectiveness: agricultural models that produce food and fiber while actively regenerating ecosystems and enhancing rural livelihoods.

By merely adjusting existing frameworks, these reforms risk reinforcing a status quo that treats degradation as a tolerable externality and labels the existential risks facing European food systems as merely 'a slowdown of productivity growth'[52]. In contrast, the transition that this study proposes, and that many pioneering farmers are already practising, requires a more foundational shift. There must be a move from accounting for externalities to designing systems that reverse them, from compensating for environmental damage to cultivating agroecosystem health as a core productive force.

Systemic Biases in TFP

Despite its widespread use, TFP has several epistemological, methodological and data-related limitations that skew its results, and consequently, its influence on policy and practice, away from the public interest.

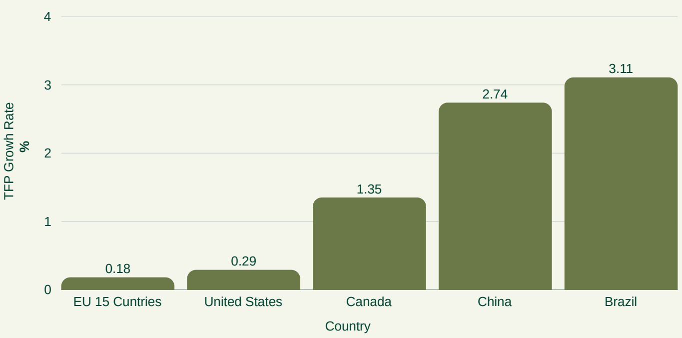

Figure 8: The average annual growth rate of different countries' TFP from 2000-2015[53]

Epistemological bias arises from TFP's emphasis on technological advancement as the primary lever in productivity growth. This downplays the agency of farmers, the role of well-educated labour, and the value of ecological stewardship. Methodological bias arises from the exclusive reliance on market-priced inputs, thereby omitting key production factors such as soil health, biodiversity and ecosystem services. These factors, while critical to long-term productivity, are not monetised, and therefore excluded from TFP calculations.

Using market prices to weigh inputs introduces a subjective bias that favours financialised, input-heavy production models, often at the expense of smaller-scale family farms. The emphasis on short-term profit maximisation encourages mechanisation, labour reduction and ecological exploitation (for example, through practices like ploughing to release 'free' nutrients via mineralisation). This creates a destructive feedback loop in which those who exploit land and labour most aggressively are rewarded with faster land accumulation, displacing other approaches.

In addition, market prices are not neutral indicators. They are shaped by government subsidies, trade regimes and monetary policies. Market prices also systematically discount the future by failing to incorporate externalities. The historic overuse of the plough exemplifies this problem[54]: while it initially boosts productivity, it has repeatedly led to land degradation and civilizational collapse[55].

The Agricultural Treadmill

The combined effects of these biases have contributed to two major systematic outcomes: the concentration of land ownership and environmental degradation, collectively encapsulated in the concept of the "agricultural treadmill"[56]. This treadmill diminishes national strategic autonomy, undermines innovation and public health, and accelerates the decline of rural livelihoods. This is a development trajectory that historically contributed to the collapse of smallholder farming in classical civilisations and ushered in exploitative feudal systems[57]. In this light, TFP serves less as a true indicator of productive efficiency and more as a steward of the agricultural treadmill.

51 Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., & Foley, J. A. (2012). Recent patterns of crop yield growth and stagnation. Nature communications, 3(1), 1293.(LINK)
52 OECD. (2023). Agricultural Policy Monitoring and Evaluation 2023: Adapting Agriculture to Climate Change. OECD Publishing. (LINK)
53 Data source: U.S. Department of Agriculture, Economic Research Service. (n.d.). International agricultural productivity. (LINK)
54 Lal, R., Reicosky, D. C., & Hanson, J. D. (2007). Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil and tillage research. (LINK)
55 Montgomery, D. R. (2012). Dirt: The erosion of civilizations (2nd ed.). University of California Press.
56 Cochrane, W. W. (1958). Farm prices: myth and reality. U of Minnesota Press. (LINK)
57 Hudson, M. (2020). Debt, land and money: From Polanyi to the new economic archaeology. In Karl Polanyi and twenty-first-century capitalism (pp. 135–154). Manchester University Press. (LINK)

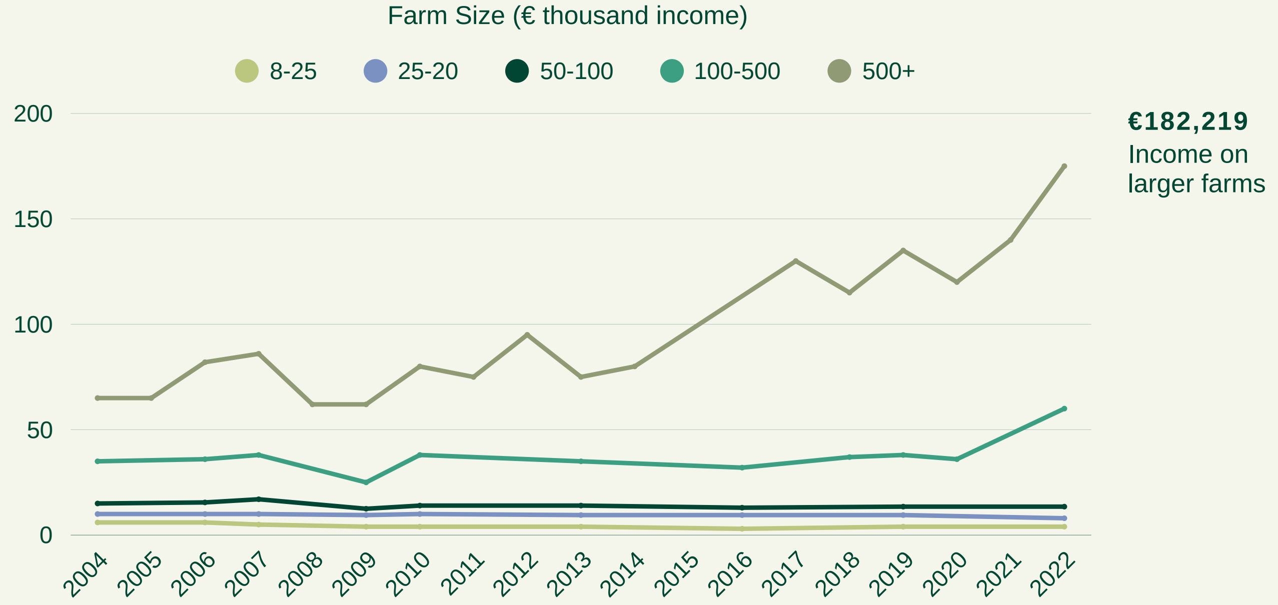

Figure 9: Larger farms have had greater income growth (income per full-time worker by farm size)[58]

Misleading Signals from 'High Performance'
The prioritisation of technology as a driver of productivity growth has led to misleading interpretations. For example, the OECD attributes decades of agricultural output growth to more efficient input use. However, it fails to distinguish between different types of input and their long-term sustainability. TFP treats land like any other input, without accounting for soil degradation or off-farm land use.

"For many decades, total agricultural production in the OECD grew at rates well above the growth of use of inputs (like land and fertiliser), with the main source of growth coming from more productive ways of combining inputs. However in the last 10 years, productivity growth has slowed down, with production continuing to increase but the use of variable inputs, such as agrochemicals, remaining at a constant level."[59]

This is evident in countries like Denmark and the Netherlands[60] which show high historical TFP growth[61] but also rank among the worst in Europe for nitrogen emissions[62], nitrate water pollution[63], biodiversity loss[64] and greenhouse gas emissions[65] per hectare.

58 The Guardian. Revealed: the growing income gap between Europe's biggest and smallest farms. (LINK)
59 Bureau, J. and J. Antón (2022), "Agricultural Total Factor Productivity and the environment: A guide to emerging best practices in measurement", OECD Food, Agriculture and Fisheries Papers, No. 177 (LINK)
60 European Commission. Productivity in EU agriculture - slowly but steadily growing. (LINK)
61 USDA. (2025), International Agricultural Productivity (2025). (LINK)
62 European Environment Agency. Nitrate Concentration in Groundwater (LINK)
63 Sutton et al., (2011). European nitrogen assessment - Technical Summary. (LINK)
64 Albuquerque et al., (2012). European Bird Distribution is "well" represented by Special Protected Areas: Mission accomplished?. Biological Conservation. (LINK)
65 Gołasa et al., (2021). Sources of Greenhouse Gas Emissions in Agriculture, with Particular Emphasis on Emissions from Energy Used. Energies. (LINK)

In reality, the apparent efficiency gains are often obtained through unsustainable intensification.

A compelling alternative analysis comes from Meino Smit, who provides a full accounting of Dutch agricultural productivity[66]. His findings show that while output increased by 17% over several decades, total inputs rose by 700%, driven largely by intensification based on fossil fuels. Dutch agriculture relies on over 3 million hectares of foreign land to supply animal feed, far exceeding the 1.8 million hectares of agricultural land within the Netherlands. The societal costs of this system, estimated at 5-20 billion annually, exceeds the sector's net added value of 6.3 billion in 2020[67].

Towards Regenerating Full Productivity (RFP)
This study responds to these challenges by proposing RFP as an evolved methodology that integrates biophysical, ecological and, indirectly, social dimensions of agricultural performance. RFP draws from TFP's strengths but moves beyond its limitations by valuing non-market production factors and enabling a transition from eco-efficiency to eco-effectiveness.

Rather than simply trying to reduce harm, RFP is designed to capture and incentivise agricultural systems that actively regenerate ecosystems, empower farmers and sustain communities. It seeks to support a policy and measurement framework capable of aligning agricultural productivity with Europe's broader ecological and social objectives.

66 Smit, M. (2018). De duurzaamheid van de Nederlandse landbouw: 1950–2015–2040 (Doctoral dissertation, Wageningen University and Research). (LINK)
67 Smit, M. (2018)

1.3.3 Closing remarks on related works

Ultimately, the scope and context-specificity of populations analyzed in any agricultural study or productivity assessment are of highest relevance. The data selected from the spectrum of possibilities plays a decisive role in determining the use value of productivity assessments and future scenarios of agricultural systems.

Standard problems with trial sites and long-term farm observatory projects lie within their selection criteria, which do not include any significant systematic performance indicators. This applies, for instance, to the German soil inventory with more than 3000 sites across Germany. It fails to produce meaningful context-specific deltas or spectrums of the existing performance distribution of the farmers. Limited by the laws of statistics and Roger's theory[68] of innovation, these assessments tend to reflect only the average, conventional farmer. Moreover, they overlook the empirically observed and future potential of agricultural pioneers, whose results remain undervalued or overlooked due to the small sample size relative to the total farming population.

It is insightful to reflect on how the agricultural sector has built such a negative bias against its own innovation capacity. This problem has a long history, arguably starting with Marcus Porticus in the western hemisphere and with Sang Hongyang in the eastern hemisphere, continued in the west by the influential - though utterly unscientific - Malthusian discourse on population growth in the 19th century that sidelined productivity growth potential through the notion of crippled rural capacities to innovate.

68 Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovation in an integrated approach to communication theory and research (pp. 432-448). Routledge. (LINK)

"When we discuss the productive developmental trajectory of computer chips, we ignore the average diffused chip performance, preferring to look at the latest high-performing chips and compare them to the best chips 5, 10 or 15 years ago. If agricultural pioneers had the platform to show their high performance, we would have the same enthusiasm and thus investment into the future of agriculture as is incited by the powers of computing technology - with much higher benefits to society at large."

Simon Krämer, Executive Director of EARA and lead author of the study

2 Epistemology, Methodology, and Data

2 Epistemology, Methodology, and Data

This chapter sets out the epistemological and methodological foundations of the RFP index, developed to advance the core objectives of this research. It outlines the data collection strategy, practical constraints and reflections on broader applicability. The overriding goal has been to develop an approach that maximises use value for policy-makers, industry and farmers alike. Knowledge production and science should be assessed not only by disciplinary criteria, but also by their relevance, scope and contributions to the public interest.

2.1 Epistemology: Land, Knowledge and the Political Economy of Productivity

Our epistemological approach adopts a longue durée[69] perspective on agricultural knowledge, grounded in the political ecology of land, biogeochemical cycles and human innovation. As discussed in the previous chapter, the conventional modelling approach of TFP has significant shortcomings, based on its definition of productivity framed by market-priced inputs and outputs. Instead, the RFP methodology takes a more multidimensional and systematic approach, proven to be applicable and scalable in practice[70].

Inadequacy of market price framing
RFP avoids assessing systematic productivity solely on the basis of market prices, while still considering their influence. Farmers understand from experience that market prices are not an indicator of efficiency. They are deeply shaped by monetary policy, fiscal regimes, speculation, subsidies and geopolitical trade instruments[72]. More crucially, prices fail to capture ecological thresholds or biophysical limits, and do not reflect the needs of present and future generations for food, fibre, water, clean air and public health.

In short, market prices are neither inelastic nor scientifically neutral, they are instruments of allocation in an economic system often misaligned with ecological and social imperatives of peace and health[73].

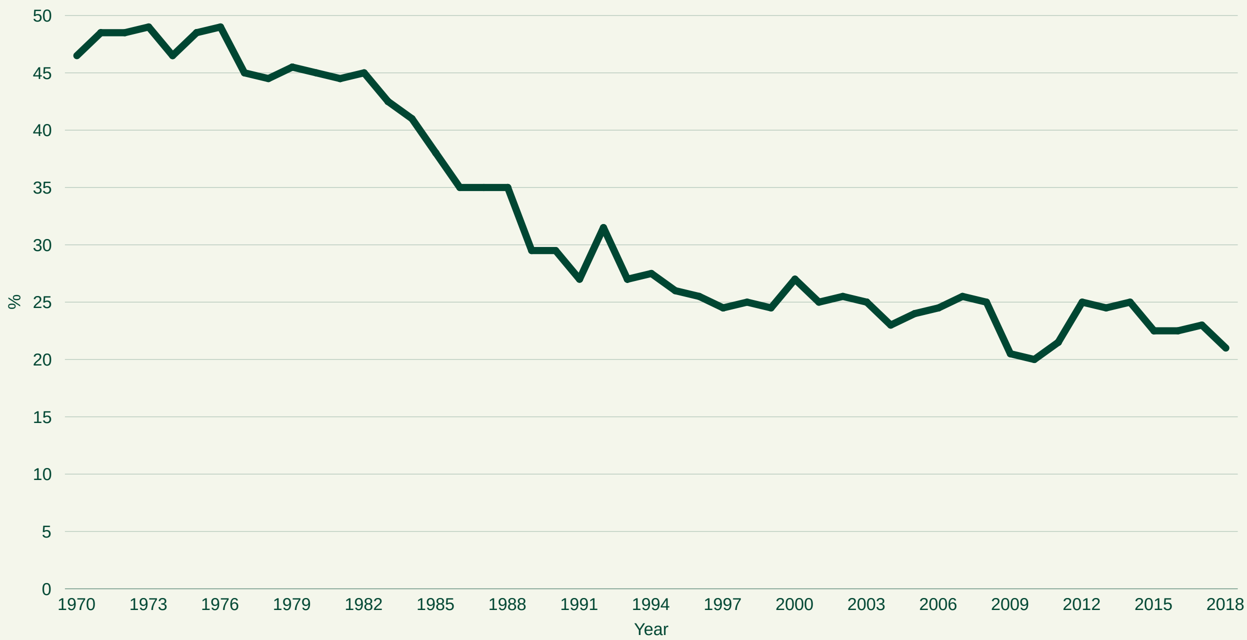

Figure 10: Trends of 'real prices' received by farmers for agricultural produce in Germany[71]

69 Lee, R. E. (Ed.), & Wallerstein, I. M. (Trans.). (2012). The longue durée and world-systems analysis. State University of New York Press.
70 Demonstrated in private sector application of a similar on-farm RegenAg SaaS in multiple government projects and quickly scaling beyond 250,000 ha of application on all 5 continents. For example: Work on data interoperability with entire machinery industry, Fraunhofer and more, which is our basis for work on the Fieldpass. (LINK), GRDC (Australian Grain Grower Development Center) work on data interoperability based on ATLAS (LINK)
71 Thünen Institute (2023). Die Landwirtschaft in der Lebensmittel-Wertschöpfungskette. (LINK)
72 This is especially true in the inherently volatile market of agriculture, where monetary and fiscal policies currently play a critical role. Consequently, the idea of an objective assessment of productivity via market prices and rational choice actors is misleading.
73 Tomalka et. al. (2024). Stepping back from the precipice: Transforming land management to stay within planetary boundaries. Potsdam, Germany: Potsdam Institute for Climate Impact Research. (LINK)

Land as a foundational epistemic anchor
RFP centres land as the most fundamental and inelastic production factor. Adopting the argument of Swiss economist Mathias Binswanger[74], agricultural performance must be assessed in relation to land's biophysical and social productivity, not its exchange value. The unit of analysis in RFP is Utilised Agricultural Area (UAA), with all productivity benchmarks calculated per hectare, retrofitted to specific contexts (i.e. pedoclimatic conditions) by design.

Context specificity and standardisation
Because land productivity is highly dependent on pedoclimatic conditions (far more than on labour quantity, technology or capital), our methodology emphasises contextual retrofitting[76]. This allows for meaningful performance comparisons that can speak to the local needs of farmers as well as those of policy makers. Pedoclimatic conditions are context-specific and must be accounted for in any meaningful performance benchmarking or comparison. Whereas TFP primarily attempts to compare agricultural performance at nation state level, the RFP is grounded in the context-specificity of place, to allow a meaningful comparison at all levels. Performance results are benchmarked by assessing context-calibrated relative performance differences per UAA.

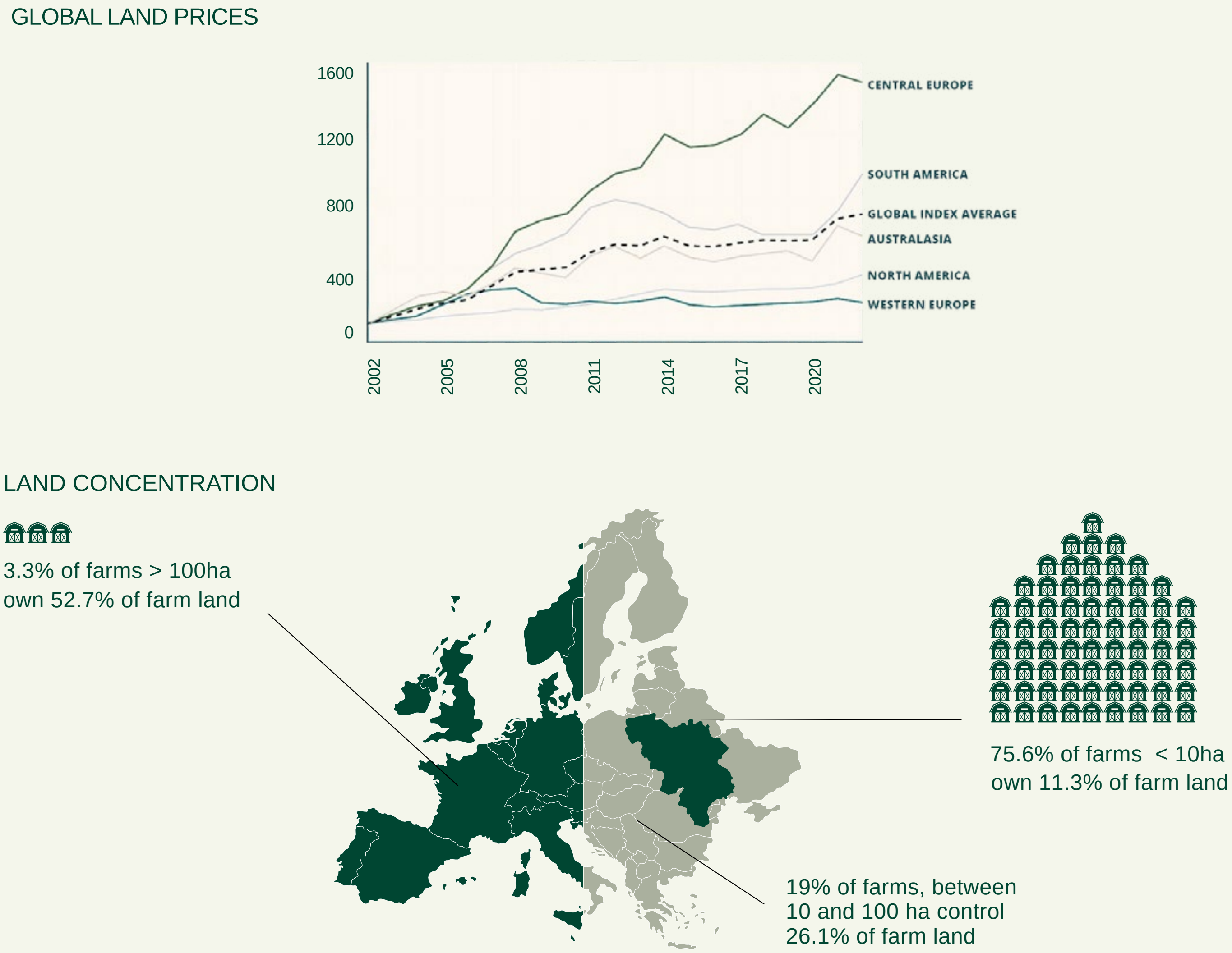

Figure 11: Development and state of land concentration and prices[75]

74 Binswanger, M. (2020). Mehr Wohlstand durch weniger Agrarfreihandel: Landwirtschaft und Globalisierung. Picus Verlag. (LINK)
75 Glass, J., McMorran, R., & Thomson, S. (2019). The effects associated with concentrated and large-scale land ownership in Scotland: a research review. Scottish Land Commission. (LINK);
Savills. (2023). Farmland values around the globe continue to rise. (LINK)

76 Giannakis, E., & Bruggeman, A. (2015). The highly variable economic performance of European agriculture. Land use policy, 45, 26-35. (LINK)

Labour quality as a decisive factor
Contrary to conventional economic assumptions, it is not the quantity or cost of agricultural labour that most strongly determines land productivity, but its quality. High-performing stewards optimise land use by applying deep, context-specific knowledge and embracing diversification strategies. This includes systems such as vertically layered ecosystems (where different crops are stacked across canopy levels) and bio-intensified and integrated systems, such as multi-species grazing or diverse crop mixes that are spatially and temporally synchronised. Such approaches multiply the productive capacity of land not through increased external inputs, but by leveraging ecological synergies and therefore effectively creating ‘more land per cubic meter’.

In this context, the education and knowledge of land stewards becomes a critical independent determinant shaping the productivity of agricultural land. That is particularly true for highly-skilled farm labor, which incorporates an understanding of use value (in terms of ecological and social function) alongside exchange value (in market terms), as informed by political ecological economics[77].

The Regenerating Full Productivity (RFP) index integrates labour quality not by evaluating specific practices, but by measuring results, particularly in terms of diversification, integration and biological intensification across the utilised agricultural area (UAA).

While technology and labour quantity – as emphasised in standard Total Factor Productivity (TFP) models – also influence productivity, they tend to do so in linear terms. In contrast, exponential gains in full productivity (encompassing soil health, biodiversity, and resilient yields) depend on the capacity of farmers to optimise living systems. This has long been recognised, from foundational agricultural studies such as Kropotkin (1884)[78] and King (1910)[79], to more recent work such as Smit’s studies and the evaluation of a Polyface Farm-style system applied in Spain[80]. This pilot study reinforces those findings: ecological literacy and strategic land stewardship are decisive for unlocking the full potential of regenerative systems.

Technological processes are not neutral
Technological tools like precision farming can yield vastly different outcomes depending on the intention, knowledge and ecological literacy of the user. Used narrowly, they reduce input inefficiencies for minor linear advancements; used regeneratively, they enable exponential transformations in land function, soil health and system resilience[81]. Thus, the most meaningful variable is not the presence of technology, but its integration with ecological purpose and labour competence.

2.1.1 Photosynthesis, Soil Microbiome, Healthy Eating and One Health

Regenerating forms of agriculture have the potential to significantly increase soil microbiome vitality and health, which enhances the nutritional quality of food and its capacity to support human health[82].

A growing body of research links depleted soils, industrial agriculture and poor diets to the rise in non-communicable diseases (NCDs). Even by conservative estimates, more than 25% of all NCDs stem from harmful land use, agricultural practices[83] and food systems[84]. In the EU, just two major categories of NCDs - cancer and cardiovascular diseases - cost over 307 billion annually (and rising sharply[85 86]). Decreasing the risk of these two NCDs is therefore already valued at more than 436€ per hectare of EU UAA annually, based on current costs of two NDCs alone. Regenerating forms of agriculture should therefore be recognised not only as an ecological imperative but also as a foundational public health intervention.

This study aims, alongside other related efforts, to demonstrate that increasing NPP and photosynthetic efficiency while increasing soil cover and reducing harmful agricultural inputs can decrease this risk of NCDs. The underlying mechanism is the potential to strengthen immune system function through improved nutrient density and reduced toxic exposure in food systems. In the second phase of this research project, we will begin empirical data collection to further investigate and validate this connection. A more detailed discussion on the connection between human and soil health can be found in Appendix 1.

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77 Use value concerns the “practical utility” of a good – how it meets human needs (i.e., land has use value when it can support our food systems or ecological health). Exchange value refers to the “price” of a good – what it can fetch on the market, which is driven by scarcity and market dynamics rather than its usefulness. Modern society has prioritised exchange value at the expense of use value - driving extractive and reductionist financialization of all and everyone.
78 Kropotkin, P. (1888). The industrial village of the future. The nineteenth century, 23, 513-530. (LINK)
79 King, F. H. (1911). Farmers of forty centuries, or, Permanent agriculture in China, Korea and Japan. (LINK)
80 European Commission. LIFE programme: Manual for the design and implementation of a regenerative agri-food model: the Polyfarming system (LINK)
81 The difference lies in whether precision farming technology is used to slightly reduce synthetic fertilizer and pesticide inputs or whether it is applied for more transformative purposes, such as precision and intensive cover cropping that benefits soil health and crop nutrition, lowers costs and has an eco-effective impact on the land.
82 Montgomery et al., (2022). Soil health and nutrient density: preliminary comparison of regenerative and conventional farming. (LINK)
83 Ramkumar et al., (2024). Food for thought: Making the case for food produced via regenerative agriculture in the battle against non-communicable chronic diseases (NCDs). One Health, 100734. (LINK)
84 für Gesundheit, B. (2024). Zahlen und Fakten zu nichtübertragbaren Krankheiten. (LINK
85 European Commission. Cost of Non-communicable diseases in the EU (LINK)
86 European Commission. Ageing Europe - statistics on health and disability.(LINK)

2.1.2 National Economic Indexes, Phytomass, Soil and Syntropy

In the broader discourse of national economics, especially within degrowth, steady-state (doughnut) and well-being economic paradigms, RFP offers a foundational and biophysical index for assessing the true developmental condition of human ecologies and economies.

RFP is thus a pragmatic lens that has been missing so far in novel work on regenerating development and societal well-being/becoming/doing, impressively exemplified in 'Regenerative Development and Design'[88], a study commissioned by the Belgian Federal Public Service for Health, Food Chain Safety and Environment - also prevalent in a wide and growing literature (Wahl[89], Fullerton[90], Hawken[91], Lovins[92], and others).

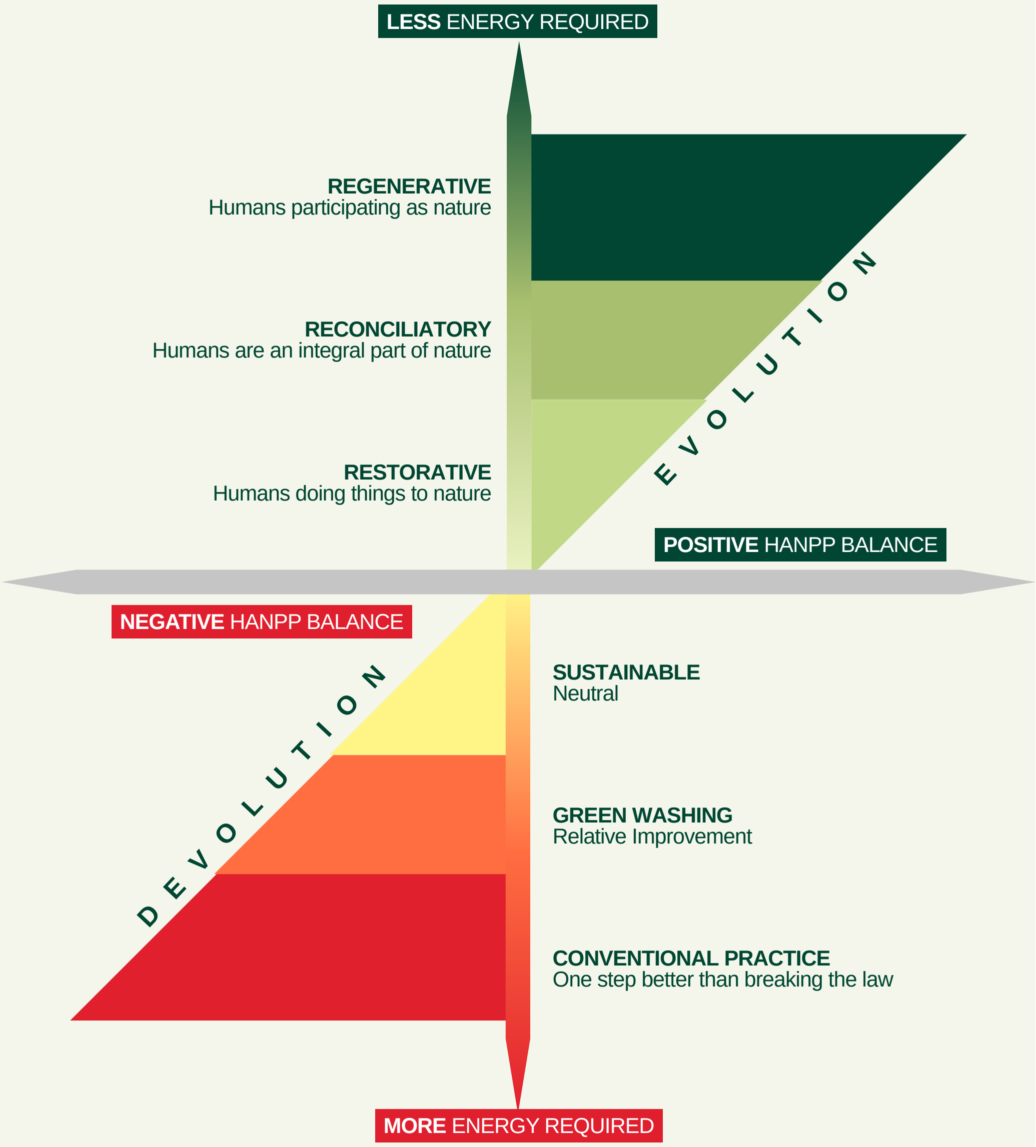


Figure 12: Regenerating land use and evolution[87]

87 Adapted from Belgian Federal Public Service for Health, Food Chain Safety and Environment. Regenerative Development and Design (LINK)

88 Belgian Federal Public Service for Health, Food Chain Safety and Environment. Regenerative Development and Design (LINK)
89 Wahl, D. C. (2016). Designing regenerative cultures. Triarchy Press. (LINK)
90 Fullerton, J. (2015). Regenerative capitalism. Capital Institute: Greenwich, CT, USA, 1-120. (LINK)
91 Hawken, P., Lovins, A. B., & Lovins, L. H. (2013). Natural capitalism: The next industrial revolution. Routledge. (LINK)
92 Lovins, A. (2013). Reinventing fire: Bold business solutions for the new energy era. Chelsea Green Publishing. (LINK)

As humans, our choices shape our environment, deciding who we are and how we interact with others - this context we create shapes us in turn. Ensuring the health and survival of future generations depends on whether our societies can start regenerating the processes that support life. Farmer-led regeneration of full productivity can guide humanity away from the precipice we are pushed to today (exploitation, starvation and the extinction of human, animal plant life on earth) and into the holistic regrow of regenerating health.

A critical starting point is the observation that human civilisation has halved the planet's living biomass (phytomass) over the last 2000 years[93]. This is not a marginal statistic: phytomass is the material basis of food systems, habitat for biocultural diversity, and the fuel for the biosphere's biochemical engines. Halving phytomass means halving the Earth's capacity to support life, regulate climate and regenerate ecosystems. To make matters worse, industrial modernity has added toxicity to scarcity. The latest Planetary Health report shows that exploitative, degenerative land use is the single largest driver behind crossing 6 of 10 planetary boundaries[94].

Alternative economic paradigms critique GDP and emphasise the need for eco-efficiency, drawing on thinkers like Georgescu-Roegen's and the concept of entropy[95]. However, they frequently overlook a central biophysical imperative: the need to regrow living biomass; both phytomass and its functional expression, Net Primary Productivity (NPP).

93 Global phytomass stocks derived from:
Adams et al. (1990). Global climate change and U.S. agriculture. Nature, 345(6272), 219–224. (LINK)
Adams, J. M., & Faure, H. (1998). A new estimate of changing carbon storage on land since the last glacial maximum, based on global land ecosystem reconstruction. Global and Planetary Change, in press. (LINK);
Saugier, B., Roy, J., & Mooney, H. A. (2001). Estimations of global terrestrial productivity: Converging toward a single number? In B. H. Walker & W. L. Steffen (Eds.), Global change and terrestrial ecosystems (pp. 543–557). Cambridge University Press.;
Houghton, R. A. (2003). Why are estimates of the terrestrial carbon balance so different? Global Change Biology, 9(4), 500–509. (LINK)
Houghton, R. A., & Goertz, H. (2008). Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. Ecological Economics, 65(3), 471–487. (LINK)
94 Planetary Health Check 2024: Report. (LINK)
95 Pueyo, S. (2014). Ecological econophysics for degrowth.Sustainability, 6(6), 3431-3483. (LINK)

This regrowth of vital living plants is not a technical detail, but the core of a peaceful, healthy and just bioeconomy. RFP serves as an applied, evidence-based index of biocultural regeneration, grounded in ecological productivity, place-based stewardship and reciprocal kin-centric relationships[96]. Decisively, regrowth of co-evolutionary regeneration of biocultural diversity is inherently the degrowth of the false binary nature / culture segregation and antagonization.

This study argues for a more meaningfully differentiated approach to economic transformation: we must be able to measure what societies ought to degrow, and equally what should be regrown. A regenerating economy cannot simply shrink its footprint; it must expand its capacity to restore and regenerate. Stewarding the biosphere means not only minimising harm, but actively participating in the regeneration of phytomass, soil organic carbon, biocultural diversity, harmony and syntropy. This is not a return to the past, but a forward-looking imperative rooted in what we now understand about our own history and how living systems work[97].

96 Salmón, E. (2000). Kincentric ecology: Indigenous perceptions of the human–nature relationship. Ecological applications, 10(5), 1327-1332. (LINK)
97 See for example Johnston, L. J. (2022). Architects of abundance: Indigenous regenerative food and land management systems and the excavation of hidden history (Doctoral dissertation, University of Alaska Fairbanks). (LINK).

"The Southern Lights farm economic and ecological performance builds up on the impact of 40 years of organic and 10 years of regenerative agroforestry practices, and thus clearly constitutes an economically and ecologically resilient pathway for farmers. With EARA we are pioneering ways to help ever more farmers embark on similar journeys."

Sheila Darmos, EARA Farmer, Co-Founder and Managing Director of The Southern Lights non-profit organization and Regenerative Farming Greece

Throughout history, societies that lived in reciprocity with their ecosystems, often organised around principles of shared stewardship, decentralised and matristic governance[98], contributed to increased net primary productivity and soil carbon accrual. Emerging insights from archaeology, soil science, and historical ecology offer important lessons for designing a regenerative economy rooted not in extractive imperatives, but in ecological participation and co-evolution (see figure 13).

There is now growing scientific evidence that regrowing NPP may be more important to planetary health than reducing hydrocarbon emissions alone[99]. Fundamentally, hydrocarbons are the fossil legacy of ancient NPP. It is photosynthesis, living plants and vital microbiomes that jointly cool, moisturise and stabilise the climate. It is plant productivity that fuels biodiversity, drives biogeochemical cycling, and enables detoxification and resilience across ecosystems. Strategically increasing NPP through regenerating land use systems offers a biologically feasible, socially beneficial pathway towards ecological stability, one more grounded and inclusive than abrupt emissions cuts that risk negative impacts on human well-being.

In this context, the RFP index is proposed not only as a tool for agricultural benchmarking, but as a foundation for rethinking national economic performance itself. Regenerating land stewardship, centred on phytomass recovery, soil formation and syntropic systems, must be seen as the heart of a truly prosperous and secure socio-economic future.

98 Scholars have identified alternative social models rooted in care, equity, and cooperation, contrasting with dominant hierarchical paradigms. Marija Gimbutas (1991) described matristic societies as prehistoric cultures centered on nurturing, life-affirming values and gender balance. Carol Gilligan (1982) introduced the ethic of care, emphasizing empathy, relational responsibility, and context-based moral reasoning. Riane Eisler (1987) proposed the partnership model, a framework in which societies value mutual respect, nonviolence, and cooperation over domination. These concepts align with the African philosophy of Ubuntu, which prioritizes shared humanity and collective well-being (“I am because we are”), still practiced today in communities like Ganvié in Benin, a lake village known for its matrilineal traditions and cooperative social life. Gimbutas, M. (1991). The civilization of the goddess: The world of Old Europe. HarperSanFrancisco, Eisler, R. (1987). The chalice and the blade: Our history, our future. Harper & Row., Gilligan, C. (1982). In a different voice: Psychological theory and women‘s development. Harvard University, Yakubu, P. (2023). The floating village of Ganvié: A model for socio-ecological urbanism. ArchDaily. (LINK)

99 It goes without saying that the latter is nevertheless of highest importance. Historically, humanity has caused more total emissions by land use change and agriculture than by using fossil fuels. See i.e. the work of Professor Rattan Lal.

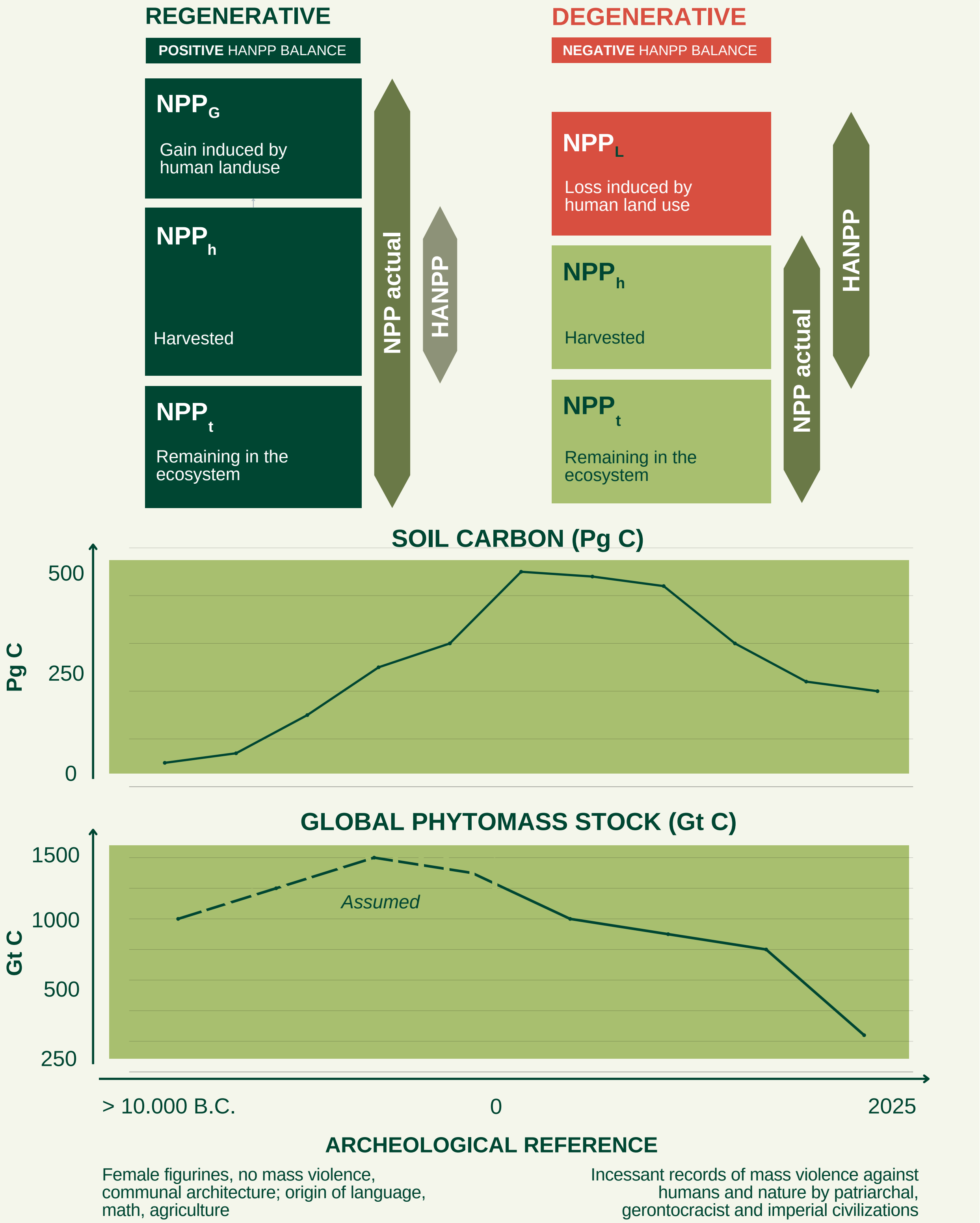


Figure 13: Regenerative and degenerative land use's coevolution with the earth's phytomass, soil organic carbon stocks and human social organization[100]

100 Based on Wieder, W. R., Bonan, G. B., & Allison, S. D. (2020). The age distribution of global soil organic carbon stocks. Nature Geoscience, 13(6), 436–441.(LINK)
Sanderman, J., Hengl, T., & Fiske, G. J. (2017). Soil carbon debt of 12,000 years of human land use. Proceedings of the National Academy of Sciences, 114(36), 9575–9580.(LINK)
And on archeology based on
Riane Eisler has proposed the term gilana (from the Greek gy-l-andros) to refer to a social system with gender equality, but with a matrilinear mode of generation. It was practised in Greece, Etruria, Rome, Basque Country, for example. Marija Gimbuntas has done extensive research on the same sociological phenomena and calls gilana matristic societies.
See i.e.
Eisler, R. (1987) The chalice and the blade – Our history, our future. Harper & Row, New York.
Gimbutas, M. (1991). The Civilization of the Goddess: The World of Old Europe. HarperSan-Francisco.
Derlet, M., & Foster, J. (2013). Invisible women of prehistory: Three million years of peace, six thousand years of war. Spinifex Press.

2.2 Methodology

The specific objectives of this study's methodology are:

1. Document farmers' innovation results by developing a comprehensive productivity index: Regenerating Full Productivity (RFP)
2. Test the RFP on pioneering farms benchmarked against context-specific average farmers, at multiple scales (crop and field, national, European)
3. Assess the measurability of RFP using simple, robust and cost-effective methods.

Overview of the RFP Index
At the heart of our methodology lies the Regenerating Full Productivity (RFP) index: a multidimensional, farmer-led innovation designed to evolve beyond conventional TFP approaches. The RFP framework is developed through the synergistic integration of TFP principles with numerous assessment methodologies for regenerating forms of agriculture (such as Ecological Outcome Verification (EOV)[101], Regenified[102], Regeneration Index[103], and many more).[104]

The RFP index is designed to capture the full productivity performance of land management by integrating both market-priced and non-market production factors. It is intended to be operationally viable for public governance, and agronomically meaningful for farmers.

RFP expands upon standard TFP indicators by incorporating proxies for:

- Soil health (photosynthesis, soil cover, pesticide use)
- Biodiversity and plant diversity (photosynthesis, soil cover, pesticide use, biomass spatial standard deviation)
- Water quality and availability (soil cover, surface temperature, evapotranspiration, pesticide use)
- Toxicity levels (pesticide use, eutrophication)

Indicator Design and Grouping
The RFP index evaluates objectively measurable results of land management performance. All indicators have been co-developed by farmers and researchers, and are grouped into two primary categories:

1. Economic indicators, and
2. Ecological indicators

At this stage, we have intentionally excluded a standalone social category, due to the complexity of identifying objectively measurable social indicators. However, positive trends in ecological and economic domains often serve as proxies for social improvements. For example, higher gross margins can support better farmworker pay, and lower toxicity combined with greater food diversity can improve community health outcomes. A deeper exploration of social indicators will be included in the next phase of this research project.

Each indicator has been selected to meet multiple criteria:

- Cost-effectiveness;
- Fitness for purpose;
- Robustness for measuring efficiency and effectiveness; and
- Optimal robustness, usefulness and efficiency attributes of indicators' measuring, processing and storing technology

This ensures that the RFP's Measuring, Monitoring, Reporting and Verification (MMRV) framework can support the broader transition to regenerating forms of agriculture, by enabling farmer creativity and biocultural diversity, while securing accountability through transparent measurement and validation of results.

101 EOV
102 Regenified
103 Regeneration Index
104 Regenerative Organic Certification

A complementary benchmarking report comparing these methodologies will be published by EARA in Q3 of 2025.

Context-Specificity and Comparative Validity
To ensure meaningful comparisons across farms and landscapes, the RFP explicitly integrates context-specific pedoclimatic conditions into its methodology. All assessments are conducted on a per-hectare of UAA basis, comparing the RFP of pioneer farms (or any farm, field or hectare), against a context-retrofitted benchmark. This approach improves the relevance and fairness of comparisons, particularly when assessing performance across highly diverse European agroecosystems. The specific formulas and retrofitting exercise can be found in Appendix 3.

Regenerating Full Productivity Index **Europe**

	Category	Indicator	Weighing	Relative Difference to Benchmark	Benchmarked Category Results
Economical	Yield and Income	Kcal	x1	- %	- %
		Protein	x1	- %	
		Gross Margin	x1	- %	
	Inputs	Fuel	x1	- %	- %
		Nitrogen	x1	- %	
		Phosphor	x1	- %	
		Pesticides	x1	- %	
		Feed	x1	- %	
Ecological	Water	Evapotranspiration	x1	- %	- %
		Avg Surface Temp	x1	- %	
	Climate	Fuel	x1	- %	- %
		Nitrogen	x1	- %	
		Photosynthesis	x1	- %	
		Soil Cover	x1	- %	
		LSU	x1	- %	
	Biodiversity	Pesticides	x1	- %	- %
		Photosynthesis	x1	- %	
		Soil Cover	x1	- %	
		Plant Diversity	x1	- %	

Regenerating Full Productivity Performance - %

Figure 14: Regenerating Full Productivity Index

Indicators: Yields, Gross Margin and Inputs

In our analysis, we aligned the pioneer survey data with the Eurostat categorisations, retrofitting our survey structure accordingly while accounting for national specificities, limitations and differences in priorities, depth of differentiation and country-specific exceptions (e.g., Mediterranean crops, cotton, fallow land and water data). For feed, we account for the difference of non-national feed use by pioneers compared to the corresponding national average. These adjustments and the detailed retrofitting process are transparently documented in Appendix 3, covering nationally compounded pioneer raw data, benchmarking data and retrofitting details. The discussion section will further explain the individual indicators, data resolution, limitations and potentials. Where sufficient comparison data of average farmers in a scope and context is missing, the indicator in the index calculations has been temporarily not accounted for.

The RFP assesses the two core remote-sensed indicators of whole year photosynthesis and soil cover performance. The RFP also integrates complementarity via remote-sensing surface temperature and evapotranspiration in critical, heat prone times (May-September) of the year or place, alongside whole-year plant diversity.

Indicators: Photosynthesis and Soil Cover

For yearly performance assessments of photosynthesis and soil cover, we utilized two scientifically validated vegetation indices, Normalized Difference Vegetation Index (NDVI) from optical satellite imagery (Sentinel-2) and Radar Vegetation Index (RVI) from radar satellite imagery (Sentinel-1), to robustly and efficiently monitor plant performance[105] and soil cover status year-round, regardless of cloud conditions[106], on a 10x10m resolution. We used a scientifically proven[107] NDVI value of 0.4 as a conservative threshold to distinguish sufficiently vegetated areas from bare or sparsely vegetated land. This threshold is well-supported in remote sensing literature. For example, Montandon and Small (2008)[108] found that even bare soils can exhibit NDVI values up to around 0.4 due to soil reflectance. Thus, using NDVI > 0.4 as a threshold ensures that only areas with true vegetation cover (beyond the contribution of bright soil background) are counted as vegetated.

Indicators: Land Surface Temperature and Evapotranspiration

Land Surface Temperature (LST) was computed using the Statistical Mono-Window (SMW) algorithm developed by Ermida et al. (2020)[109], which is implemented in Google Earth Engine for Landsat satellites on a 30x30m resolution assessing the critical summer months of May to September. Evapotranspiration potential (ETP) was calculated using the Priestley-Taylor method[110]. The method estimates potential evapotranspiration (ETP) according to the following equation: $ETP = \alpha \times (\Delta/(\Delta+\gamma)) \times (Rn-G)/\lambda$ where Δ is the slope of the saturation vapor pressure curve, γ is the psychrometric constant, Rn is net radiation, G is soil heat flux, and λ is latent heat of vaporization. Surface albedo was calculated from Landsat satellites at 30-meter spatial resolution to derive net radiation components for the energy balance calculations. This approach has been applied in various remote sensing studies and can provide reasonable estimates when adequate energy balance components are available, making it suitable for satellite-based evapotranspiration studies[111].

Indicator: Plant Diversity

At the field scale, higher spatial NDVI variability (e.g. larger within-field standard deviation of NDVI) indicates vegetative heterogeneity and is generally associated with greater plant species richness. Empirical studies[112] consistently find that fields exhibiting greater NDVI heterogeneity support more diverse plant communities. For example, Gould (2000) showed that variation in NDVI was positively correlated with measured vascular plant species richness. Thus, fields with higher within-field NDVI standard deviations (reflecting mixed crop types or natural patches) tend to harbor higher biodiversity[113]. This pattern aligns with theoretical expectations under the “spectral heterogeneity”[114] paradigm, which predicts that structural variation in vegetation (captured by NDVI statistics) corresponds to habitat heterogeneity and, in turn, higher species richness[115].

105 Mandal et al., (2020). Dual polarimetric radar vegetation index for crop growth monitoring using sentinel-1 SAR data. Remote Sensing of Environment, 247, 111954. (LINK)
106 Huang et al., (2020). Land cover mapping in cloud-prone tropical areas using Sentinel-2 data: Integrating spectral features with NDVI temporal dynamics. Remote Sensing, 12(7), 1163. (LINK).
107 Peng et al. (2019). Quantifying influences of natural factors on vegetation NDVI changes based on geographical detectors in Sichuan, western China. Journal of Cleaner Production, 233, 353-367. (LINK)
108 Montandon et al. (2008). The impact of soil reflectance on the quantification of the green vegetation fraction from NDVI. Remote Sensing of Environment, 112(4), 1835-1845. (LINK)

109 Ermida et al. (2020). Google Earth Engine open-source code for Land Surface Temperature estimation from the Landsat series. Remote Sensing, 12(9), 1471. (LINK)
110 Priestley, C. H. B., & Taylor, R. J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review, 100(2), 81-92. (LINK)
111 Yao et al. (2021). Simplified Priestley–Taylor model to estimate land-surface latent heat of evapotranspiration from incident shortwave radiation, satellite vegetation index and air relative humidity. Remote Sensing, 13(5), 902. (LINK)
112 Xin et al. (2024). High-precision estimation of plant alpha diversity in different ecosystems based on Sentinel-2 data. Ecological Indicators, 166, 112527.(LINK); Chen et al. (2023). Estimating plant species diversity using Sentinel-2 data and machine learning: A case study of subtropical forests in China. Ecological Informatics, 75, 102208.(LINK);
Madonsela et al. (2021). Tree species diversity affects remotely sensed spectral heterogeneity. Remote Sensing, 13(13), 2467.(LINK)
113 Alavi, N., & King, D. (2020). Evaluating the relationships of inter-annual farmland vegetation dynamics with biodiversity using multi-spatial and multi-temporal remote sensing data. Remote Sensing, 12(9), 1479. (LINK)
114 Gould, W. A. (2000). Remote sensing of vegetation, plant species richness and regional biodiversity hotspots. Ecological Applications, 10(6), 1861–1870. (LINK)
115 Mashiane, K., Ramoelo, A.; Adelabu, S. (2024). Prediction of species richness and diversity in subalpine grasslands using satellite remote sensing and random forest machine learning algorithm. Applied Vegetation Science, 27, e12778. (LINK)

2.2.1 Benchmarking Scopes

This study seeks to rigorously test whether farmers who apply regenerating forms of agriculture achieve significantly higher Regenerating Full Productivity (RFP) than the average, and to understand the biophysical drivers of such differences. The RFP is designed to serve as a comprehensive proxy for land performance, capturing not only yield, but also ecological and energetic efficiency.

At the core of our inquiry lies the theoretical argument that regenerating land use, particularly by enhancing photosynthetic performance, soil cover and biotic interactions, can significantly increase overall productivity when assessed holistically. Unlike conventional productivity metrics, RFP incorporates ecological functions such as carbon cycling, nutrient retention, soil water dynamics and plant-microbiome interactions via proxies as integral productivity factors.

This theoretical framing is grounded in several interlinked premises:

1. **Photosynthesis is foundational:** Higher Net Primary Productivity (NPP), driven by optimised photosynthesis, generates more biomass, root exudates and energy for food webs, directly enhancing yield and ecosystem function.

2. **Soil cover mediates multiple services:** Continuous vegetative cover improves water retention, moderates temperatures and reduces erosion, enabling both resilience and productivity.

3. **Ecological complexity improves efficiency:** Diverse agroecosystems optimise nutrient cycling and reduce the need for external inputs, thereby increasing output-to-input efficiency.

4. **Remote sensing can objectively measure key proxies:** Satellite-derived indicators can provide consistent, reproducible and scalable proxies for photosynthesis, soil cover and agroecological stress levels.

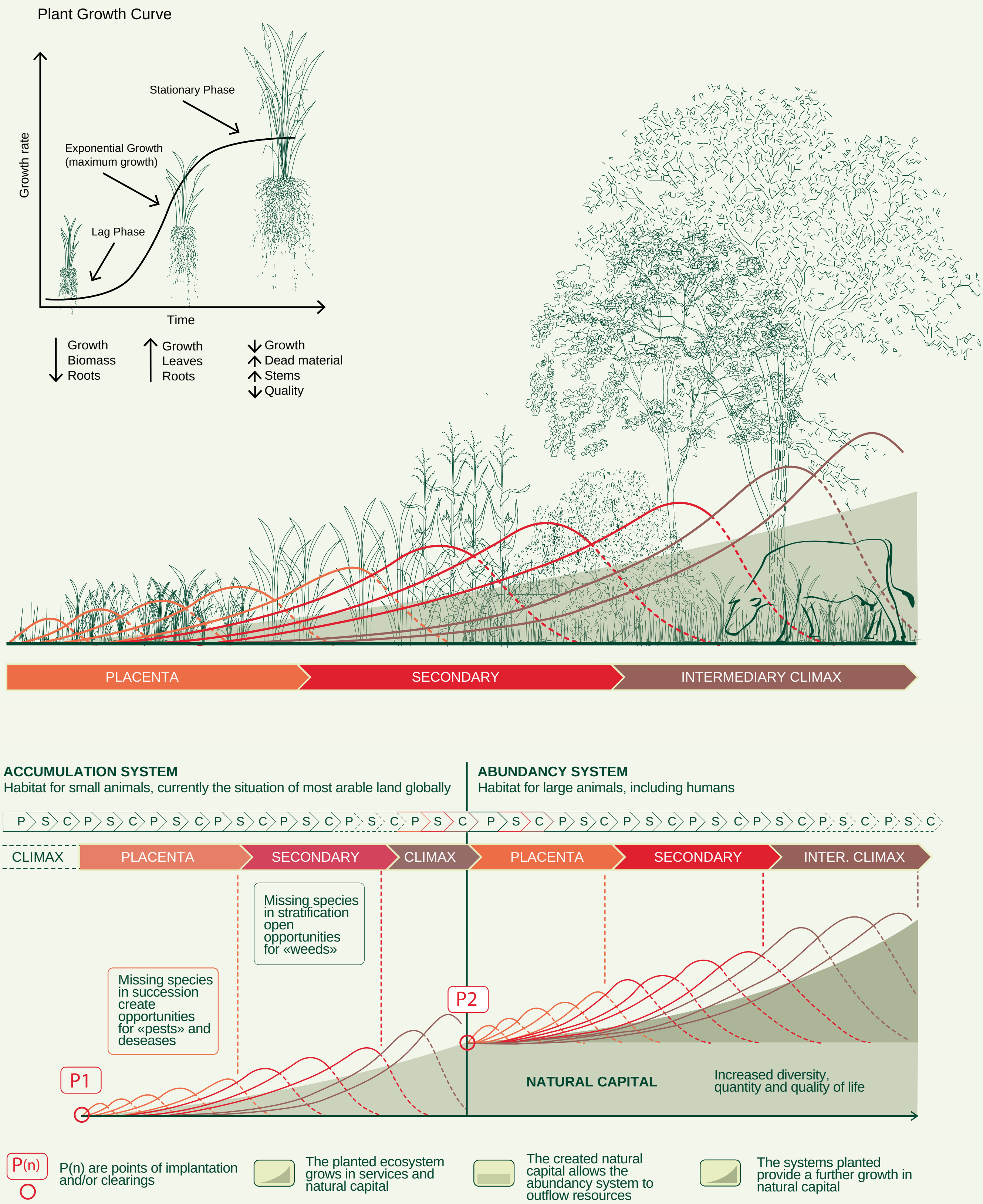


Figure 15: Photosynthesis and the s-curve development of productivity and life on earth[116]

116 Adapted from Terrasintropica. (2022, April). Syntropic farming. Wikifarmer. (LINK), Sprinkle, J. (2019). What is the right grazing management? Progressive Cattle. (LINK)

Benchmarking Scopes and Data Triangulation
To produce robust results within the resource constraints of this study, we developed a triangulated benchmarking approach across three nested spatial scopes, Field, National and European, combined with multiple data sources. This design ensures that findings are not artefacts of single contexts or methods, and supports broader generalisability.

The benchmarking scopes outlined above serve not only to validate the utility of the RFP index, but also to test the central regenerative proposition: that land can be managed in ways that regenerate ecological functions and produce more with fewer external inputs. If supported, this provides both scientific and policy justification for shifting support mechanisms towards farmers who are actively regenerating productivity in all its dimensions.

Scope 1: Crop and Field Scope

Data types:

- Detailed input / output data for a specific crop
  - Temporal coverage: One year
- Pioneer field vs. 3 neighbouring fields of same use type (via satellite)
  - Temporal coverage: 2019–2024

Purpose:
Micro-level differentiation of management results

Scope 2: Country Scope

Data types:

- Input / output data per UAA of pioneers
- Eurostat and national literature input / output data
- Pioneer qualitative survey (feed, hazards, biodiversity)
  - Temporal coverage: 2021-2023
- Satellite benchmarking (3 fields per pioneer vs. 9 random fields in same land use category and pedoclimatic region)
  - Temporal coverage: 2019–2024

Purpose:
Context-specific benchmarking of ecological and economic indicators

Scope 3: Europe Scope

Aggregated Scope 2

Purpose:
Assess European-scale differences in regenerating full productivity

2.3 Data

Data were collected, via survey, from 78 pioneering farmers, with a total of 2144 hectares, in 14 different countries for the years 2021-2023 (survey data is in Appendix 3). Complementarily, we collected an additional 5473 hectares of neighbouring comparison fields assessed by satellite analysis. Satellite data both for pioneering fields and comparison fields was assessed from 2019-2024.

Area monitored in detail for national scope (2021-2023)

Country	Participants	Average Operation Size (ha)	Area monitored by Survey (ha)
Belgium	5	63	168
Estonia	2	435	134
Finland	10	157	224
France	14	56	363
Germany	12	177	402
Greece	11	8	33
Hungary	1	532	123
Italy	7	139	60
Netherlands	2	105	19
Norway	3	53	45
Portugal	2	629	121
Slovenia	5	23	18
Spain	9	237	550
Sweden	1	851	41
Average	6	247	164

Table 1: Overview of pioneer sample

Pioneers of regenerating forms of agriculture who are stemming from Agroecology, Agroforestry, Conservation Agriculture, Organic Agriculture, Animal Husbandry, Market Gardening, Rational or Holistic Planned Grazing and other practices, all exceed in input reduction, biological improvements and yield resilience, while achieving regenerative outcomes in their particular context. By regenerative outcomes we mean the continuous improvement of all decisive productivity factors.

The farmers were identified and invited to this study by the power of Europe's Regenerating Movement. The participating farmers are part of EARA, as well as other pioneering farmer associations such as CNA[117] and ECAF[118]; in engagement with private sector pioneers like Unilever[119] and Soil Capital[120]; or regional initiatives such as the Iberian Association of Regenerative Agriculture[121], BSAG[122], Greenotec[123] or WeAreTheRegeneration[124].

117 Centre National d'Agroécologie. (Website)
118 European Conservation Agriculture Federation. (Website)
119 Unilever Global (Website)
120 Soil Capital (Website)
121 Asociación de Agricultura Regenerativa (Website)
122 Baltic Sea Action Group. (Website)
123 Greenotec (Website)
124 WeAreTheReGeneration (Website)

Crop	Belgium	Estonia	Finland	France	Germany	Greece	Hungary	Italy	Netherlands	Norway	Portugal	Slovenia	Spain	Sweden	Total
Cereals for Grain	x	x	x	x	x		x	x		x	x	x		x	x
Industrial Crops	x	x	x	x	x	x	x	x						x	x
Oil Seeds	x	x	x	x	x	x	x	x						x	x
Fiber Crops				x		x									x
Tobacco															
Hops															
Energy Crops								x							x
Root Crops	x			x					x	x					x
Dry Pulses	x		x	x	x	x	x	x	x						x
Seeds / Seedlings			x						x						x
Fallow Land Spontaneous Growth															
Green Fallow			x					x							x
Fallow Land Fresh Biomass					x										x
Fallow Land Dry Biomass		x	x	x								x			x
Bovine Meat			x	x	x		x	x		x	x	x	x	x	x
Poultry Meat								x				x	x		x
Pig Meat													x		x
Sheep & Goat Meat		x	x	x				x				x			x
Milk					x							x			x
Eggs				x				x	x			x			x
Grassland Fresh Biomass															
Grassland Dry Biomass		x	x	x	x		x			x	x		x	x	x
Vegetables incl. Melons & Strawberries				x		x			x			x			x
Fruit Vegetables									x						x
Strawberries															
Herbs / Medicinals			x						x						x
Fruits, Berries, Nuts			x			x		x				x			x
Pome Fruits												x			x
Stone Fruits															
Berries			x									x			x
Nuts						x						x			x
Citrus Fruits						x									x
Olives						x		x				x	x		x
Olives for Oil						x		x					x		x
Table Olives															
Grapes						x							x		x
Grapes for Wine															
Grapes for Raisins						x									x
Undersown Cover Crops		x	x					x				x			x
Cotton						x		x							x

Table 2: Overview of crop types collected in pioneer survey and assessed in research phase 1

Land Use Category	Pioneer Farmer (total farm)		EU Distribution	
Arable / Annual	7.377	**63%**	8.093.810	**62%**
Grassland	3.857	**33%**	47.963.710	**31%**
Perennial	527	**4%**	11.137.950	**7%**
Total	1.1761	**100%**	157.195.470	**100%**

Table 3: Comparison of land use distribution (in ha) of pioneer total farms to EU agricultural sector

„Regenerative agriculture and regenerative hydrology support year-round and systemic area-wide ecosystem use of rainwater and soil protection from erosion on land and in the landscape, which is the basis for the regeneration of water and soil resources and the restoration of territorial microclimate. They fully support the water-soil-climate system (NEXUS), which is scientifically and innovatively developed by the Freshwater Based Bioeconomy Thematic Working Group of the BioEast initiative through the updated thematic Strategic Research and Innovation Agenda (SRIA).“

Martin Kováč, Former Deputy Minister of Agriculture and Rural Development of the Slovak Republic or/and Water Holistic, principal advisor

3 Results

3 Results

This chapter presents the findings derived from the study's triangulated benchmarking approach, which spanned three nested spatial scopes, Field, National and European. By systematically analyzing data across these levels, the results aim to test the study's arguments while mitigating context-specific biases and enhancing generalisability. The structure of the findings reflects this multi-scalar design, with results organized to highlight both consistencies and divergences across the benchmarking scopes and data sources.

3.1 Crop and Field Scope

In this scope is found the highest resolution of detail on the differences in farm management, including details on fuel and specific pesticide use.

3.1.1 CASE STUDY

Tyynelä Farm, Juuso Jona

Country
Finland

Crop
Oats

Year
2022

Systems
Organic
Agroecology
Conservation Agriculture

Juuso's farm

Average neighbouring farm

Contextualized comparison of inputs an outputs per hectare

	Pioneer	Average	%
Soil Management	Minimum Tillage, Drilling	Plouging	
Service Crop	Undersown Crops, Cover Crops	None	
Inputs			
Synthetic Nitrogen	-	100 kg	**-100%**
Synthetic Phosphorous	-	7 kg	**-100%**
Synthetic Potassium	-	14 kg	**-100%**
Organic Nitrogen	42 kg	-	
Organic Phosphorous	4 kg	-	
Organic Potassium	36 kg	-	
Fuel	50l	80l	**-38%**
Pesticides	-	380 g/active substance Insecticides 80g/l active substance, Fungicides 50g/l active substance, Herbicides 250g/l active substance	**-100%**
Yields			
Oats	3250 kg	3870 kg	**-16%**
Aditional Biomass	1000 kg	-	**100%**
Gross Margin	975 €	340 €	**187%**
Satellite Data (farm level per hectare)			
Photosynthesis	35	29	**17%**
Soil Cover	50	44	**14%**

3.1.2 CASE STUDY

Southern Lights Farm, Sheila Darmos

Country
Greece

Year
2023

Crop
Olives, Lemons, Oranges, Limes

Systems
Organic
Agroecology

Sheila's farm

Average neighbouring farm

Contextualized comparison of inputs an outputs per hectare

	Pioneer	Average	%
Soil Management	No-till, Mulching, Cover Crops	Occasional Tilling	
Service Crop	Native weeds, Nitrogen-fixing crops	None	
Inputs			
Synthetic Nitrogen	-	1720 kg	**-100%**
Synthetic Phosphorous	-	266 kg	**-100%**
Organic Nitrogen	-	-	**-**
Organic Phosphorous	-	-	**-**
Fuel	75l	420l	**-82%**
Pesticides	-	363 g/active substance Insecticides 8 g/l active substance, Fungicides 5 g/l active substance, Herbicides 250 g/l active substance	**-100%**
Yields			
Limes	6.500 kg	12.500 kg	**-48%**
Lemons	5.106 kg	8.000 kg	**-36%**
Oranges	5.311 kg	24.000 kg	**-78%**
Olives	6.843 kg	1.250 kg	**447%**
Gross Margin	5.541 €	2.652 €	**109%**
Satellite Data (farm level per hectare)			
Photosynthesis	77	29	**8%**
Soil Cover	99	44	**1%**

3.1.3 CASE STUDY

Fröhlich Farm, Peter Fröhlich

Country
Switzerland

Crop
Sugerbeets

Year
2022

Systems
Conservation Agriculture
Agroforestry

Contextualized comparison of inputs an outputs per hectare

	Pioneer	Average	%
Soil Management	Strip Tilling, Direct Drilling	Ploughing	
Service Crop	2x Cover Crops with over 20 species	None	
Inputs			
Synthetic Nitrogen	40 kg	120 kg	**-67%**
Synthetic Phosphorous	40 kg	60 kg	**-33%**
Synthetic Potassium	200 kg	400 kg	**-50%**
Organic Nitrogen	-	-	-
Organic Phosphorous	-	-	-
Fuel	24l	50l	**-52%**
Pesticides	130 g/active substance Insecticides 50 g/l active substance, Fungicides 0 g/l active substance, Herbicides 80 g/l active substance	1050 g/active substance Insecticides 85 g/l active substance, Fungicides 725 g/l active substance, Herbicides 1050 g/l active substance	**-88%**
Yields			
Sugerbeets	95.000 kg	93.000 kg	**1%**
Gross Margin	1.800 €	1.500 €	**20%**
Satellite Data (farm level per hectare)			
Photosynthesis	54	48	**13%**
Soil Cover	75	67	**12%**

3.1.4 CASE STUDY

Eichhof, Felix Riecken

Country
Germany

Year
2022

Crop
Animal Production (Milking Cows)

Systems
Grass-fed in the Irish grazing system with feedmix: Gras 81%, Maize Silage, 11%, Wheat, 3%, Field bean 3%, Corn kernels 2%

In comparison to stabled system with feedmix: Maize Silage 40%, Rapeseedcake 10%, Soy 10%, Wheat 10%, Gras 30%

Contextualized comparison of inputs an outputs per hectare

	Pioneer	Average	%
Soil Management	Rotational grazing with Irish principles and agroforestry	Conventional arable cropping and grasland management	
Service Crop	The area hosts a mix of grasses, legumes, and forbs, dominated by meadow foxtail, bluegrasses, white clover, and dandelion, with added diversity from thistles, nettles, and flowering herbs. Agroforestry elements like sweet chestnut, fruit trees, and deciduous shrubs add structure, while ground layers feature common weeds and fungi.		
Inputs			
Synthetic Nitrogen	-	175 kg	**-100%**
Synthetic Phosphorous	-	61 kg	**-100%**
Synthetic Potassium	-	146 kg	**-100%**
Organic Nitrogen	55 kg	-	
Organic Phosphorous	40 kg	-	
Fuel	97l	165l	**-41%**
Pesticides	-	485 g/active substance Insecticides 20 g/l active substance, Fungicides 43 g/l active substance, Herbicides 422 g/l active substance	**-100%**
Antibiotics	0,8 mg/kg/animal weight/year	4-6 mg/kg/animal weight/year	**-84%**
Yields			
Milk (according to feedmix per hectare)	37.563 l milk/ha/year	46.200 l milk/ha/year	**-19%**
Milk (according to feedmix per hectare)	8.500 l milk/cow/year	10.500 l milk/cow/year	**-19%**
Imported Feed share (and source)	6% (from Neighbour)	30% (Germany/International)	**-80%**
Satellite Data (farm level per hectare)			
Photosynthesis	69	50	**38%**
Soil Cover	86	74	**16%**

3.1.5 CASE STUDY

KugelSüdhangHof, Christine Bajohr

Country
Germany

Year
2024

Crop
Animal Production
(Beef by Ox Fattening)

Systems
Holistic Planned Grazing (Feedmix: Grassfed + Hay in winter), Biodynamic

In comparison to Stall fattening (Feedmix: Maize Silage 70%, Rapeseed, 10%, Soy 5%, Wheat 5%, Gras/Hey 10%)

Contextualized comparison of inputs an outputs per hectare

	Pioneer	Average	%
Soil Management	Holistic Planned Grazin, compost optionally when in need	Conventional arable cropping and grasland management	
Service Crop	Highly diverse pastures with more than 45 species		
Inputs			
Synthetic Nitrogen	-	175 kg	**-100%**
Synthetic Phosphorous	-	48 kg	**-100%**
Synthetic Potassium	-	126 kg	**-100%**
Organic Nitrogen	-	-	**-38%**
Organic Phosphorous	-	-	
Fuel	40l	90l	**-56%**
Pesticides	-	1150 g/active substance Insecticides 35 g/l active substance, Fungicides 165 g/l active substan-ce, Herbicides 1150 g/l active substance	**-100%**
Antibiotics	-	5-10 mg/kg/animal weight/year	**-100%**
Yields			
Animal Production (feedmix/hectare)	597 kg carcass weight	700 kg carcass weight	**-15%**
Conversion Rate	7,5 kg dry mass/kg meat (live weight gain)	6,5 kg dry mass/kg meat (live weight gain)	**115%**
Imported Feed share (and source)	>10% (from Region)	30% (Germany/International)	**-67%**
Gross Margin	2.900,00 €	2.000,00 €	**45%**
Satellite Data (farm level per hectare)			
Photosynthesis	63	61	**3%**
Soil Cover	82	77	**6%**

3.2 National Scope

This section presents findings at the national level, offering a mid-scale and nationally context-specific perspective that bridges localized field data with broader European patterns. Analyzing trends and patterns within national boundaries allows for the identification of systemic dynamics and contextual factors that influence the study's key variables at a country-wide scale. At the national scope, varying data resolution and quantity is achieved. The details are all transparently noted in Appendix 3.

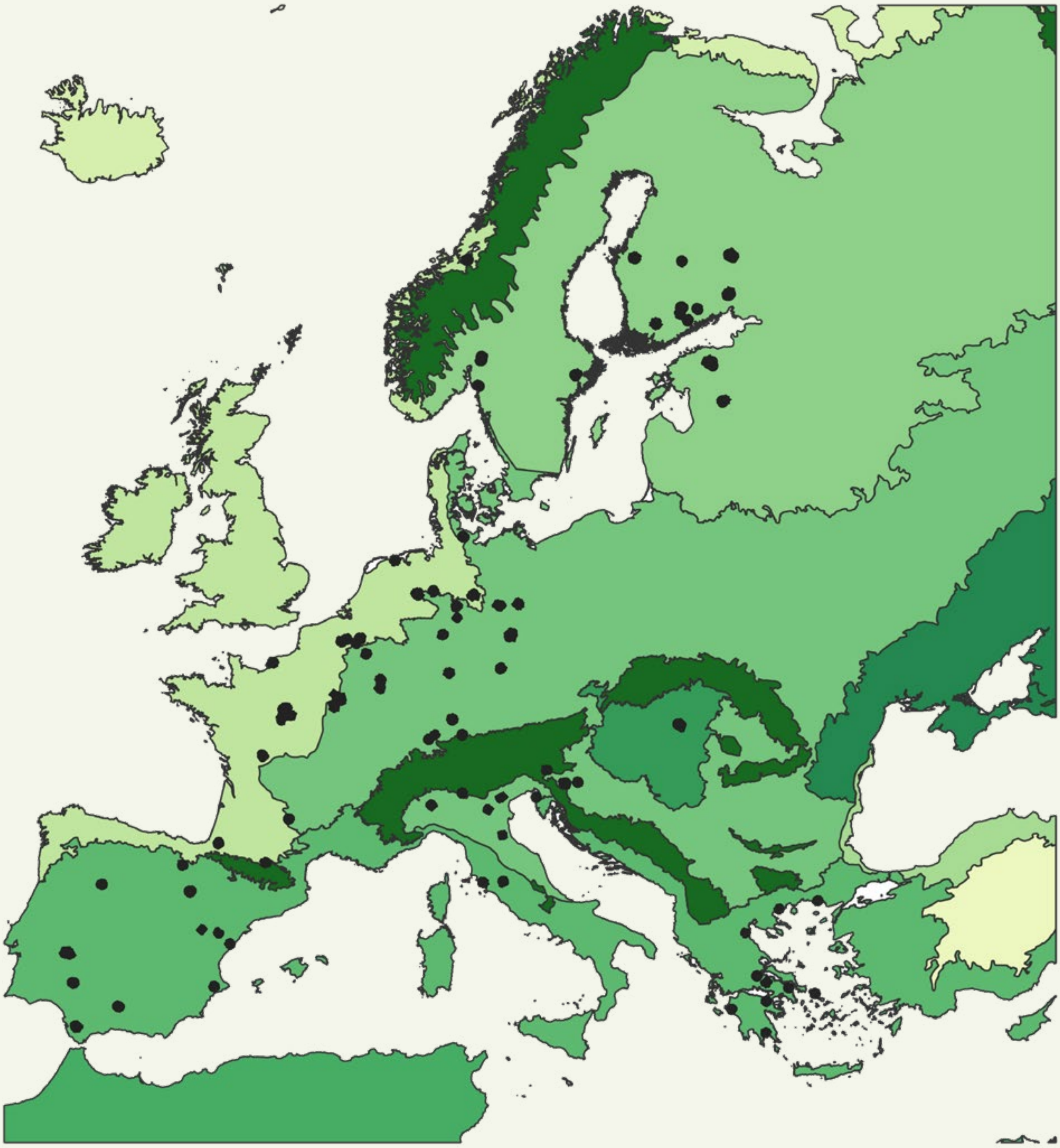
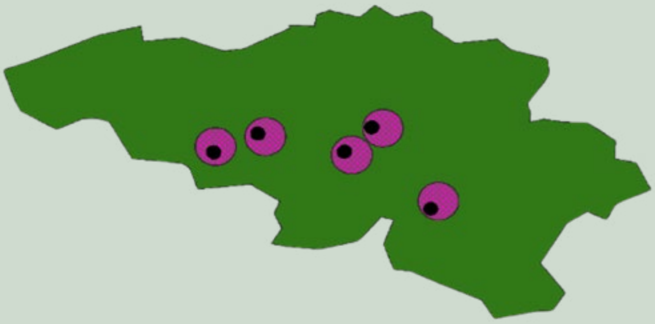


Figure 16: Overview of farmers participating in research phase 1

3.2.1 National Scope

Belgium

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Root Crops
Dry Pulses
Green Maize



+17%

Regenerating Full Productivity (RFP)
Overall Index Result

Yields

-8%**
Kilocalories

-9%**
Protein

1%
Gross Margin

Inputs

14%
Synthetic Nitrogen

63%
Mineral Phosphorus

58%
Pesticides

Water, Climate, Biodiversity

1%*
Evapotranspiration

2%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

5%
Photosynthesis

8%
Soil Cover

27%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

**** Explanatory lead Belgium regarding Yields:** Sample has no intensive livestock production whereas Beligum has one of the highest LSU / UAA in EU

3.2.2 National Scope

Estonia

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Fallow Land Dry Biomass
Sheep & Goat Meat
Grassland Dry Biomass
Undersown Cover Crops
Temporary Grassland

+13%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields	Inputs	Water, Climate, Biodiversity	
50% **Kilocalories**	-11% **Synthetic Nitrogen**	-1%* **Evapotranspiration**	12% **Photosynthesis**
47% **Protein**	-6% **Mineral Phosphorus**	1%* **Surface Temperature**	11% **Soil Cover**
-24%** **Gross Margin**	44% **Pesticides**	*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.	14% **Plant Diversity**

X% = better per ha than average farmer
-X% = worse per ha than average farmer

**** Explanatory lead Estonia regarding Gross Margin:** Very small sample with no high value crops and no intensive livestock production

3.2.3 National Scope

Finland

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Dry Pulses
Seeds / Seedlings
Green Fallow
Fallow Land Dry Biomass
Bovine Meat
Sheep & Goat Meat
Sheep & Goat Meat
Grassland Dry Biomass
Fruits, Berries, Nuts
Undersown Cover Crops

+26%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

2%
Kilocalories

3%
Protein

20%
Gross Margin

Inputs

42%
Synthetic Nitrogen

22%
Mineral Phosphorus

93%
Pesticides

Water, Climate, Biodiversity

-1%*
Evapotranspiration

3%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

14%
Photosynthesis

12%
Soil Cover

22%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

3.2.4 National Scope

France

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Fiber Crops
Root Crops
Dry Pulses
Fallow Land Dry Biomass
Bovine Meat
Sheep & Goat Meat
Eggs
Grassland Dry Biomass
Vegetables incl. Melons & Strawberries

+19%

Regenerating Full Productivity(RFP)
All indicators summarized

Yields

-17%
Kilocalories

-18%
Protein

29%
Gross Margin

100%
Regional Feed

Inputs

-6%
Synthetic Nitrogen

-29%
Mineral Phosphorus

63%
Pesticides

Water, Climate, Biodiversity

0%*
Evapotranspiration

2%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

27%
Photosynthesis

27%
Soil Cover

10%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

3.2.5 National Scope

Germany

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Dry Pulses
Fallow Land Fresh
Biomass
Bovine Meat
Milk
Grassland Dry Biomass
Green Maize

+28%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-4%
Kilocalories

-3%
Protein

-24%**
Gross Margin

100%
Regional Feed

Inputs

54%
Synthetic Nitrogen

55%
Mineral Phosphorus

90%
Pesticides

Water, Climate, Biodiversity

1%*
Evapotranspiration

-1%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

7%
Photosynthesis

11%
Soil Cover

0%***
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

**** Explanatory lead Germany regarding Gross Margin:** Sample has no vegetable and no intensive livestock production

*****Explanatory lead Germany regarding Plant Diversity:** Satellite design robustness insufficient to date, further elaborated in discussion below

3.2.6 National Scope

Greece

Crops
Industrial Crops
Oil Seeds
Fiber Crops
Dry Pulses
Vegetables incl. Melons & Strawberries
Fruits, Berries, Nuts
Citrus Fruits
Olives
Olives for Oil
Grapes
Grapes for Raisins
Cotton

+18%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-30%
Kilocalories

-30%
Protein

75%
Gross Margin

Inputs

99%
Synthetic Nitrogen

70%
Mineral Phosphorus

-41%**
Pesticides

Water, Climate, Biodiversity

10%*
Evapotranspiration

1%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

10%
Photosynthesis

8%
Soil Cover

22%
Plant Diversity

X% = better per ha than average farmer

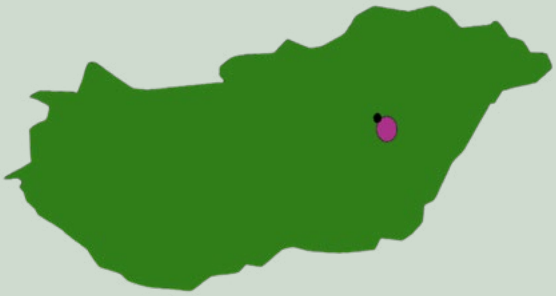
-X% = worse per ha than average farmer

**** Explanatory Lead Greece regard Pesticides:** Sample has much lower relative UAA in perennial land use than average UAA distribution in Greece

3.2.7 National Scope

Hungary

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Dry Pulses
Bovine Meat
Grassland Dry Biomass



+52%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields	Input	Water, Climate, Biodiversity	
11% **Kilocalories**	80% **Synthetic Nitrogen**	-2%* **Evapotranspiration**	79% **Photosynthesis**
14% **Protein**	38% **Mineral Phosphorus**	-2%* **Surface Temperature**	91% **Soil Cover**
-6% **Gross Margin**	91% **Pesticides**	*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.	25% **Plant Diversity**

X% = better per ha than average farmer

-X% = worse per ha than average farmer

3.2.8 National Scope

Italy

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Energy Crops
Dry Pulses
Green Fallow
Bovine Meat
Poultry Meat
Sheep & Goat Meat
Eggs
Fruits, Berries, Nuts
Olives
Olives for Oil
Undersown Cover Crops
Cotton

+44%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-9%
Kilocalories

-9%
Protein

33%
Gross Margin

100%
Regional Feed

Inputs

95%
Synthetic Nitrogen

98%
Mineral Phosphorus

83%
Pesticides

Water, Climate, Biodiversity

1%*
Evapotranspiration

1%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

25%
Photosynthesis

29%
Soil Cover

25%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

3.2.9 National Scope

Norway

Crops
Cereals for Grain
Root Crops
Bovine Meat
Grassland Dry Biomass

+36%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-8%
Kilocalories

-9%
Protein

16%
Gross Margin

100%
Regional Feed

Ecosystem Services

69%
Synthetic Nitrogen

44%
Mineral Phosphorus

100%
Pesticides

Water, Climate, Biodiversity

1%*
Evapotranspiration

3%*
Surface Temperature

*Insufficient technological re-solutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

24%
Photosynthesis

23%
Soil Cover

-4%**
Plant Diversity

X% = better per ha than average farmer

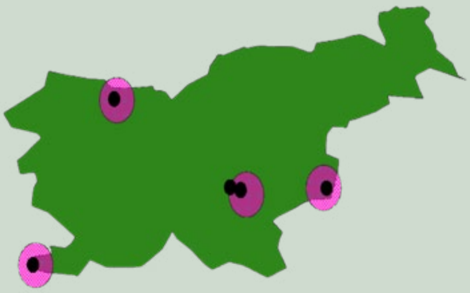
-X% = worse per ha than average farmer

****Explanatory lead Norway regarding Plant Diversity:** Satellite design robustness insufficient to date, further elaborated in discussion below

3.2.10 National Scope

Slovenia

Crops
Cereals for Grain
Fallow Land Dry Biomass
Bovine Meat
Poultry Meat
Sheep & Goat Meat
Milk
Eggs
Vegetables incl. Melons & Strawberries
Fruits, Berries, Nuts
Pome Fruits
Olives
Undersown Cover Crops
Temporary Grassland



+32%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-5%
Kilocalories

-5%
Protein

88%
Gross Margin

25%
Regional Feed

Inputs

100%
Synthetic Nitrogen

-41%**
Mineral Phosphorus

100%
Pesticides

Water, Climate, Biodiversity

1%*
Evapotranspiration

2%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

11%
Photosynthesis

9%
Soil Cover

6%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

****Explanatory lead Slovenia regarding Mineral Phosphorus:** Very small sample with no high value crops and no intensive livestock production

3.2.11 National Scope

Spain

Crops
Bovine Meat
Pig Meat
Grassland Dry Biomass
Vegetables incl. Melons & Strawberries
Olives
Olives for Oil
Grapes

+46%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-14%**
Kilocalories

-14%**
Protein

-13%**
Gross Margin

99%
Regional Feed

Inputs

90%
Synthetic Nitrogen

100%
Mineral Phosphorus

96%
Pesticides

Water, Climate, Biodiversity

3%*
Evapotranspiration

2%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

43%
Photosynthesis

38%
Soil Cover

36%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

****Explanation for Spain regarding Yield and Gross Margin:** Sample does not include any ‚high-value' vegetable crops nor 'value-adding' intensive livestock productions, but is compared to average national production per hectare, which includes a great deal of both externality-and-input-heavy production systems (e.g. Almería's 'Sea of Plastic' and >50 Mio pigs slaughtered p.a., all largely for export)

3.2.12 National Scope

Sweden

Crops
Cereals for Grain
Industrial Crops
Oil Seeds
Bovine Meat
Grassland Dry Biomass
Temporary Grassland

+35%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

25%
Kilocalories

24%
Protein

64%
Gross Margin

100%
Regional Feed

Inputs

31%
Synthetic Nitrogen

100%
Mineral Phosphorus

67%
Pesticides

Water, Climate, Biodiversity

0%*
Evapotranspiration

0%*
Surface Temperature

*Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

28%
Photosynthesis

28%
Soil Cover

1%**
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

****Explanatory lead Sweden regarding Plant Diversity:** Satellite design robustness insufficient to date, further elaborated in discussion below

3.2.13 National Scope

Netherlands

Crops
Root Crops
Dry Pulses
Seeds / Seedlings
Eggs
Vegetables incl. Melons & Strawberries
Fruit Vegetables
Herbs / Medicinals

+49%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

-22%
Kilocalories

-22%
Protein

69%
Gross Margin

100%
Regional Feed

Inputs

100%
Synthetic Nitrogen

100%
Mineral Phosphorus

100%
Pesticides

Water, Climate, Biodiversity

No water related satellite data available in Phase 1

8%
Photosynthesis

15%
Soil Cover

15%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

3.2.14 National Scope

Portugal

Crops
Cereals for Grain
Bovine Meat
Grassland Dry Biomass

+49%

Regenerating Full Productivity (RFP)
All indicators summarized

Yields

8%
Kilocalories

8%
Protein

-42%**
Gross Margin

Inputs

100%
Synthetic Nitrogen

100%
Mineral Phosphorus

100%
Pesticides

Water, Climate, Biodiversity

No water related satellite data available in Phase 1

53%
Photosynthesis

23%
Soil Cover

18%
Plant Diversity

X% = better per ha than average farmer

-X% = worse per ha than average farmer

****Explanatory lead Portugal regarding Gross Margin:** Sample has no wine or vegetable production nor 'high-value' adding externality heavy conventional chicken or pig production

3.3 European Scope

This section outlines the results at the European scale, providing a comparative perspective across multiple national contexts. By synthesizing patterns across countries, this scope highlights broader structural trends and cross-national variations, offering insights into the wider applicability and relevance of the study's findings.

Regenerating Full Productivity Index

Europe

	Category	Indicator	Weighing	Relative Difference to Benchmark	Benchmarked Category Results
Economical	Yield and Income	Kcal	x1	-2%	6%
		Protein	x1	-2%	
		Gross Margin	x1	20%	
	Inputs	Fuel	x1	- %	69%
		Nitrogen	x1	61%	
		Phosphor	x1	51%	
		Pesticides	x1	75%	
		Feed	x1	87%	
Ecological	Water	Evapotranspiration	x1	1%	1%**
		Avg Surface Temp	x1	1%	
	Climate	Fuel	x1	- %	37%
		Nitrogen	x1	61%	
		Photosynthesis	x1	25%	
		Soil Cover	x1	24%	
		LSU	x1	- %	
	Biodiversity	Pesticides	x1	75%	35%
		Photosynthesis	x1	25%	
		Soil Cover	x1	24%	
		Plant Diversity	x1	16%	

Regenerating Full Productivity Performance **33%***

*Presenting here the average of all single country RFP scores assessed

**Insufficient technological resolutions in Phase 1. Details can be found in the Discussions chapter at the end of the report.

Index	Belgium	Estonia	Finland	France	Germany	Greece	Hungary
Kcal	-8%	50%	2%	-17%	-4%	-30%	11%
Protein	-9%	47%	3%	-18%	-3%	-30%	14%
Gross Margin	1%	-24%	20%	29%	-24%	75%	-6%
Fuel							
Nitrogen	14%	-11%	42%	-6%	54%	99%	80%
Phosphorous	63%	-6%	22%	-29%	55%	70%	38%
Pesticides	58%	44%	93%	63%	90%	-41%	100%
Feed				100%	100%		
Evapotranspiration	1%	-1%	-1%	0%	1%	10%	-2%
Surface temp	2%	1%	3%	2%	-1%	1%	-2%
Fuel							
Nitrogen	14%	-11%	42%	-6%	54%	99%	80%
Photosynthesis	5%	12%	14%	27%	7%	10%	79%
Soil Cover	8%	11%	12%	27%	11%	8%	91%
LSU							
Pesticides	58%	44%	93%	63%	90%	-41%	100%
Photosynthesis	5%	12%	14%	27%	7%	10%	79%
Soil Cover	8%	11%	12%	27%	11%	8%	91%
Plant Diversity	27%	14%	22%	10%	0%	22%	25%
Participating countries RFP	**17%**	**13%**	**26%**	**19%**	**28%**	**18%**	**52%**

	Italy	Norway	Slovenia	Spain	Sweden	Netherl.	Portugal	AVERAGE	Lowest	Highest
Kcal	-9%	-8%	-5%	-14%	25%	-22%	8%	**0%**	-30%	50%
Protein	-9%	-9%	-5%	-14%	24%	-22%	8%	**1%**	-30%	47%
Gross Margin	33%	16%	88%	-13%	64%	69%	-42%	**10%**	-24%	75%
Fuel										
Nitrogen	95%	69%	100%	90%	31%	100%	100%	**39%**	-11%	99%
Phosphorous	98%	44%	-41%	100%	100%	100%	100%	**30%**	-29%	70%
Pesticides	83%	100%	100%	96%	67%	100%	100%	**58%**	-41%	100%
Feed	100%	100%	25%	99%		100%		**87%**	100%	100%
Evapotranspiration	1%	1%	1%	3%	0%			**1%**	-2%	10%
Surface temp	1%	3%	2%	2%	0%			**1%**	-2%	3%
Fuel										
Nitrogen	95%	69%	100%	90%	31%	100%	100%	**39%**	-11%	99%
Photosynthesis	25%	24%	11%	43%	28%	8%	53%	**22%**	5%	79%
Soil Cover	29%	23%	9%	38%	28%	15%	23%	**24%**	8%	91%
LSU										
Pesticides	83%	100%	100%	96%	67%	100%	100%	**58%**	-41%	100%
Photosynthesis	25%	24%	11%	43%	28%	8%	53%	**22%**	5%	79%
Soil Cover	29%	23%	9%	38%	28%	15%	23%	**24%**	8%	91%
Plant Diversity	25%	-4%	6%	36%	1%	15%	18%	**17%**	0%	27%
Participating countries RFP	**44%**	**36%**	**32%**	**46%**	**35%**	**49%**	**49%**	**25%**	13%	52%
Average Participating countries RFP	**33%**									

Table 4: RFP overview of country and European scopes

3.4 Strategic result-based indicator influence overview: Photosynthesis and Soil Cover to other RFP indicators

To assess if the indicators photosynthesis and soil cover can function as strategic result-based indicators, that operationalized in a context-specific way, can serve as anchor of public payments for public goods, the study assess the difference of RFP results in which photosynthesis and soil cover are excluded to the average of photosynthesis and soil cover performance.

Case Studies:

Christine	Felix	Sheila	Juuso	Peter	Average
67%	44%	82%	61%	40%	69%

Countries:

Belgium	Estonia	Finland	France	Germany
14%	2%	18%	11%	25%
Greece	**Hungary**	**Italy**	**Norway**	**Slovenia**
12%	45%	23%	16%	29%
Spain	**Sweden**	**Netherlands**	**Portugal**	**AVERAGE**
7%	10%	52%	17%	20%

Table 5: Influence description of strategic result-based indicators photosynthesis and soil cover as relative difference of RFP without photosynthesis and soil cover indicators to the average of photosynthesis and soil cover indicators

Table 5: shows that with existing data it can be stated that the influence as relative difference is relatively consistent, never inverse, and not overwriting the other important productivity results such as food yield across case studies and countries. The difference in influence between case studies and countries can be explained by the higher yields and gross margins of case studies relative to country RFPs. Their relatively higher yields and gross margins can be explained by the study's explicit selection bias for the case studies that most impressively demonstrate the range of the innovative leap of the most advanced examples of regenerating forms of agriculture.

4 Discussion

4.1 Data Limitations

Although this study may represent the most extensive systematic empirical dataset on regenerating forms of agriculture to date, the principal limitation remains the relatively small number of pioneering farmers who were able to share their data. Data sharing is a time-intensive process, and family farms are structurally disadvantaged in this regard due to lower capital expenditure (and therefore less digitalisation) and the absence of dedicated administrative staff.

Except in Finland, we lacked the financial or institutional capacity to remunerate farmers for the opportunity costs associated with data provision. Despite the efforts of our researchers to support on-farm data collection, these opportunity costs remained the primary constraint on broader participation.

In the second phase of this study, we aim to (1) increase the number of participating farmers, (2) collect more granular data from current participants, and (3) strengthen collaboration with public and private initiatives that are already engaging with similar data collection efforts.

Although the survey was developed by farmers and researchers jointly, many concepts differ in farmer knowledge and also national data availability across Europe. Researchers have put specific care into each farmer and their survey contributions, as well as into harmonizing concepts and terms across both pioneer and comparison data sets. Nevertheless, this underlying disharmony in terminology introduces a risk on the precision of the data used in the analysis. The learnings of this first phase will be integrated into the data collection in the continuation of this research.

4.2 Methodological Considerations and Biases Observer and Self-Selection Bias

Observer and Self-Selection Bias
All scientific research is shaped by the frameworks and tools employed. In the social sciences, self-selection bias is a particularly relevant concern. It occurs when individuals voluntarily participate based on traits correlated with the study's outcomes, undermining the ability to hold other variables constant (ceteris paribus).

Self-selection bias occurs when individuals voluntarily sort themselves into groups based on characteristics related to the study's outcome, rather than being randomly assigned. This undermines the ceteris paribus condition (holding all else equal) because systematic differences[125] between groups may drive the observed effects rather than the variable under investigation[126].

This study is unavoidably affected by self-selection. However, this bias is also intrinsic to our research aim: to understand the frontier of agricultural innovation. Rogers' theory of innovation diffusion suggests that to study transformative practices one must focus on early adopters and innovators; by definition, a self-selected group[127].

Moreover, data collection required analytical record-keeping and time investment by the farmers, introducing further bias toward those with higher education levels, greater digital literacy and higher incomes. As such, our sample likely underrepresents marginalised, lower-income and less digitally-integrated farmers.

Survivor Bias
This study also carries survivor bias: we did not attempt to track farmers who abandoned regenerative practices or exited farming altogether. Given the broad pressures facing European agriculture, with tightening regulatory burdens, declining terms of trade and limited access to land or capital, such exits may not correlate with regenerative transition failures. Analogously, aerospace or computing innovations are not assessed by the number of failed prototypes, but by the performance leap of successful ones.

Field Selection Protocol
When asking farmers to share their three best fields, farmers were told to specifically not choose the fields where they had the best soil quality and highest yields, but to choose those fields where the impact of their regenerating management has had the greatest effect, since they started such changes in management.

4.3 Representativeness of the Sample

To evaluate representativeness, we compared the soil fertility potential of pioneer farms against national averages using the EU LUCAS soil data. As proxy for soil fertility potential, we used SOC/Clay ratio and SOC[128] concentration. We associated the pioneering farms with all LUCAS reference points in a 30km radius of the farm (usually 1 and sometimes 2 data points).

The analysis shows that pioneering farms are, on average, located on more degraded soils than the

125 Elwert, F., & Winship, C. (2014). Endogenous selection bias: The problem of conditioning on a collider variable. Annual review of sociology, 40(1), 31-53. (LINK)
126 Heckman, J. J. (1979). Sample selection bias as a specification error. Econometrica: Journal of the econometric society, 153-161. (LINK)
127 Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. An integrated approach to communication theory and research (pp. 432-448). Routledge. (LINK)
128 Feeney et al (2024). Benchmarking soil organic carbon (SOC) concentration provides a more robust soil health assessment than the SOC/clay ratio at European scale. Science of The Total Environment, 951, 175642. (LINK)

national mean. This implies a conservative bias in performance benchmarking, as the baseline for improvement was lower.

The distribution of Utilised Agricultural Area (UAA) by use type (e.g., arable, grassland, specialty crops) among pioneers was broadly in line with national and EU averages (see table 3). Outliers have been acknowledged and discussed by the research team and participants. These are attributed to the small sample size relative to Europe's total farming population and the inherent variability of farming systems, and made transparent in the retrofitting details in the Appendix 3. Further, the study has touched on almost all crops of the EU agricultural sector.

4.4 Index Weighting

During the formulation phase, certain indicators (e.g., photosynthesis, soil cover) appeared in multiple indexes. This multiple appearance may create an impression that these indicators are overrepresented in the final RFP calculation. From a mathematical standpoint, this perception is inaccurate, as the appearance of an indicator in more than one index does not result in a compounding effect in the aggregated RFP. Each index is calculated independently before averaging into the RFP, and the repetition of indicators across indexes does not affect their influence unless explicitly weighted differently. In addition, table 4 shows that these indicators actually have the opposite effect in our sample on total RFP scores.

4.5 Retrofitting for input and output benchmarking

Land Classification
Eurostat defines land categories based on management practices (e.g., tillage), but regenerating forms of agriculture often employ diversified and multifunctional systems that do not align neatly with this taxonomy. We reclassified land by dominant output type: arable (large-scale crops), grassland (biomass and livestock), specialty annuals (vegetables and herbs) and specialty perennials (e.g. orchards).

For benchmarking, we retrofitted these classifications to Eurostat categories using guidance from the Agriculture Glossary and the Annual Crop and Animal Production Statistics Handbooks (for details see Appendix 3). For example, herb yields from market gardens were mapped into vegetable categories, and bundled output values were proportionally disaggregated. These conversions enabled consistent benchmarking of kcal and protein yields relative to UAA. Though vegetables are often undervalued in nutritional conversions, their high gross margins and low land footprint (1.2% of Europe's total UAA in 2022)[129] balanced their role in the RFP.

Gross Margin and Gross Value Added
While Eurostat provides Gross Value Added (GVA) for the agricultural sector, our study focused on Gross Margin per hectare, which excludes subsidies and thus more accurately reflects farm-level business performance. On average, EU farmers receive a minimum amount of 200€ per ha in subsidies[130]. For comparability, we conservatively added €100/ha to pioneer margins in our benchmarking.

The gross margin that land use management achieves per hectare is, if not consumed by taxes and capital expenses (debt servicing), the amount that agricultural labor can use for its own recreation and regeneration, as well as investments in the farm. The more we increase the complexity of land use systems, the more use value can the hour of agricultural work produce. The comparison of gross margin and gross value added is not clean in economic terminology. However, GVA is the closest comparative data freely available in Eurostat. The differences in definition of gross margin and GVA were attempted to be mitigated as much as possible by defining gross margin in the survey as 'Monetary Yield as Gross Margin per hectare (€) Gross Margin = yield per ha * price received per unit - direct costs such as seed, chemical, fertiliser, machinery cost (fuel + repairs and maintenance), insurance and casual labour. In the next phase of this research, we intend to incorporate Standard Gross Margins (SGM) as a more detailed measure of agricultural profitability that exists in EU statistics. However, access to the microdata required for SGM calculations is restricted to recognized research institutions under Eurostat's guidelines. As EARA is not yet formally recognized as such, we attempt to achieve that before the second research phase.

Our samples over-represented high-value crops (e.g., nuts, vegetables) and under-represented livestock finishing operations, which are common in the EU but often externality-heavy. Many pioneers also engage in short food supply chains and receive price premiums. We view these differences not as distortions but as evidence of more resilient and socially desirable farm systems: less import-dependent, more locally integrated and fairer in value distribution.

Feed Inputs and Livestock Benchmarking
For livestock yield benchmarking, we researched the main feed imports per country, as well as the total UAA used for livestock feed in the countries where our pioneer sample had significant livestock yields. In our survey, we

129 European Commission. The fruit and vegetable sector in the EU - a statistical overview - Statistics Explained (LINK)
130 European Commission. (2023). Income support explained. (LINK)

asked farmers on the share of external feed as well as the source of that feed.

In order to assess external feed input use and feed origin patterns, percentage values were calculated at three analytical levels: farmer, country and total sample. For each farmer and year (2021, 2022, 2023), the external feed input percentage was computed as the mean of reported values across all three plots. For the three-year average per farmer, the mean was taken across all available plots and years. Country-level percentages were then derived by averaging the respective farmer-level percentages per year, and across all three years. The total sample-level figures (i.e., across all countries) followed the same logic, with yearly values calculated as the mean across all individual farmers for that year, and the three-year average reflecting the mean of all available values across farmers and years.

Feed origin data was handled with proportional weighting in cases where multiple answers were given (e.g., an A,B response was treated as 50% A and 50% B). For each farmer and year, the share of each origin type was calculated by dividing the number of times a given origin was selected by the total number of origin responses for that farmer in that year. Three-year averages at the farmer level were computed using the same method across all three years. Country-level feed origin proportions were calculated by summing the number of responses per origin category across all farmers in the country and dividing by the total number of origin responses for that country and time period. For the full sample, origin shares were calculated by aggregating raw origin counts from all individual farmers, per year and across all three years, without relying on country-level percentages, to ensure that each farmer's responses were weighted equally in the total distribution. The sources for national comparison data are documented in Appendix 3.

Fuel

The crop and field level scope shows that pioneering farmers use significantly less fuel (38-82%) per UAA. In the survey, the pioneer's fuel use per hectare was collected. Unfortunately, both Eurostat and national data on fuel use in the land use of agriculture is extremely scarce to non-existent. Hence at this point a comparative figure beyond the crop & field level scope could not be produced. However, data both from the literature[131] and the crop & field level scope clearly indicate significant reductions throughout all production types.

131 Freitag, M., Friedrich, T., & Kassam, A. (2024). The carbon footprint of Conservation Agriculture. International Journal of Agricultural Sustainability, 2331949. (LINK); LIFE programme: Manual for the design and implementation of a regenerative agri-food model: the Polyfarming system (LINK)

Country	Year	Pioneers						Country Average
		Average % imported feed of total feed	Imported from neighbour	Imported from local context	Imported from national source	Imported from international source	% international feed imported	% of total feed imported internationally
France	2022	70%						
	2023			100%	100,0%		0%	55%
Germany	2021	8%	43%	57%				
	2022		20%	80%			0%	60%
	2023		20%	80%				
Italy	2021		100%					
	2022	30%	100%				0%	65%
	2023		100%					
Netherlands	2021				100%			
	2022	80%			100%		0%	53%
	2023				100%			
Slovenia	2021		14%	14%	14%	57%		
	2022	35%	13%		38%	50%	0%	75%
	2023		13%		25%	63%		
Spain	2021		29%	57%	13%	1%		
	2022	48%	29%	57%	13%	1%	0%	70%
	2023		29%	57%	13%	1%		
Norway	2021		100%					
	2022	12%	100%				0%	55%
	2023		100%					
Portugal	2021		50%	50%				
	2022		50%	50%				
	2023		50%	50%				
	Total	**34%**	**42%**	**28%**	**22%**	**8%**	**0%**	**62%**

Table 6: Overview of livestock feed sources and shares of pioneers and national average

Pesticides

In this study, pesticide input intensity was assessed by collecting detailed data from pioneering farms, including both application rates and the specific active substances used, standardized as grams of active substance per hectare. This approach allowed for a nuanced analysis of both the quantitative and qualitative aspects of pesticide use. For benchmarking purposes, Eurostat data was used on pesticide sales per hectare of utilized agricultural area. However, these aggregate figures do not account for variations in toxicity, persistence nor environmental risk among different active substances, limiting their comparability, especially in systems aiming to reduce harmful inputs or substitute them with lower-risk alternatives.

In contrast, national indicators such as Denmark's Pesticide Load Indicator (PLI)[132] offer a more differentiated assessment by applying substance-specific weightings based on ecotoxicological risk profiles. However, the PLI also has limitations, relying on detailed data that can sometimes be favorable for one substance that is just registered at a lower maximum dose. It also does not capture formulation-specific factors, nor concentration and bioactivity. These simplifications can obscure meaningful distinctions between products and lead to inconclusive or misleading interpretations, particularly in nuanced systems like regenerating forms of agriculture.

132 European Commission, Joint Research Centre. (2024, November 14). COIN Open Day – Pesticide Load Index (PLI). Knowledge4Policy. (LINK)

To address these gaps, a second phase of this study will attempt a more refined approach by grouping active substances according to their chemical classes and quantifying the total amount applied per group. This method is based on the premise that within-group variation is generally small, and that significant differences, where they exist, are often due to inconsistencies or strategic design choices in underlying assessment protocols, rather than intrinsic properties of the substances themselves. While exceptions will be acknowledged, this classification strategy provides a more chemically and toxicologically-grounded alternative to current EU-level metrics, which often lack transparency and specificity. The data needed to conduct this analysis are already publicly available, and leveraging them will allow for a more meaningful comparison of pesticide profiles across production systems. In doing so, the next phase of the study aims to contribute to the development of more robust, risk-based pesticide indicators that better reflect the realities of diverse agricultural practices.

4.6 Livestock and their units per hectare

Livestock remains a contested issue in sustainability debates, yet its ecological role is fundamental. Grazing herbivores co-evolved with grasslands to stabilise Holocene climate conditions. When managed holistically and rationally, livestock enhance soil health, plant diversity and productivity[133].

While RFP is designed to account for emissions via hectare per large-stock unit (LSU), these are often outweighed by positive ecological impacts, particularly where livestock are well integrated. Because of survey limitations, this study has been unable to produce LSU figures and comparisons in this first phase of the research. In the second phase, figures will be collected and combined with animal welfare analysis for demonstrating the trend towards higher LSU in holistic and rational systems correlating with both superior RFP performance and stronger year-over-year gains, compared to less livestock-intensive pioneers. Recent research studies show that well-managed livestock can be climate and nature efficient[134] and positive[135].

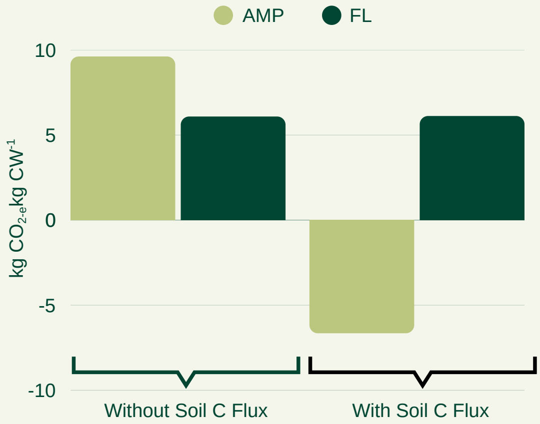


Figure 17: CO2-e GHG-balance per kg carcass weight of beef in different production systems (AMP=Adaptive multi paddock grazing; FL=feedlot) – before (left) and after (right) net C flux from soils (sequestration and erosion) is incorporated[136]

133 Retallack, G. J. (2022). Soil grown tall: The epic saga of life from Earth. Springer Nature. (LINK)
134 Sustainable Food Trust. (2025). Grazing Animals Report. (LINK)
135 Wei et al. (2023). Grazing facilitates litter-derived soil organic carbon formation in grass-lands by fostering microbial involvement through microenvironment modification, CATENA, Volume 232, 2023, 107389, ISSN 0341-8162 (LINK);
Busenitz, K. M., Schmid, R. B., & Lundgren, J. G. (2025). Regenerative rangeland manage-ment improves honey bee health and productivity. Frontiers in Sustainable Food Systems, 9, 1555238. (LINK);
Mosier et al.. (2021). Adaptive multi-paddock grazing enhances soil carbon and nitrogen stocks and stabilization through mineral association in southeastern US grazing lands. Journal of En-vironmental Management, 288, 112409. (LINK);
McGrawet al. (2024). Breeding bird response to adaptive multi-paddock and continuous grazing practices in the Southeastern United States. Ecosphere, 15(12), e70107. (LINK);
Mosier et al. (2022). Improvements in soil properties under adaptive multipaddock grazing relative to conventional grazing. Agronomy Journal, 114(4), 2584-2597. (LINK);
Teague et al. (2016). The role of ruminants in reducing agriculture's carbon footprint in North America. Journal of Soil and Water Conservation, 71(2), 156-164. (LINK);
Gomez-Casanovas et al. (2021). A review of transformative strategies for climate mitigation by grasslands. Science of the Total Environment, 799, 149466. (LINK)
136 Paige et al. (2018) Impacts of soil carbon sequestration on life cycle greenhouse gas emis-sions in Midwestern USA beef finishing systems, Agricultural Systems, Volume 162, (LINK)

4.7 Remote-sensed indicators

An in-depth discussion of error assessment, methodology and the prospects and limitations of satellite technology is provided in Appendix 1.

The analysis of pioneer and comparison fields was conducted by an external remote sensing intelligence provider, formerly known as AgriCircle[137]. This company is currently evolving into AgriPurpose: a steward-owned, purpose-driven joint venture uniting farmers, industry stakeholders and NGOs.

Our remote sensing sample comprised 256 pioneer fields and 781 comparison fields, totalling 7480 hectares. The average field size was 7.12 hectares over pioneer and comparison fields.

For photosynthesis and soil cover performance, we used DORA, a product developed by AgriCircle. DORA is an agronomic decision-support tool that evaluates plant performance and soil cover using satellite-derived metrics. It applies advanced yet accessible indicators derived from satellite imagery to provide actionable insights at the field level.

Photosynthesis and soil cover
The photosynthesis and soil cover results yielded statistically significant differences between pioneer and comparison fields. Based on internal validation, we calculated an error range of approximately 1.4% to 6.2% for these assessments. Importantly, error margins decrease with larger field sizes. Given that our sample had an average field size of about 7.12 hectares, we estimate that applying the same methodology to the European average field size of 17.1 hectares would reduce the error range to approximately 1.0% to 3.6%. Further methodological details are available in Appendix 1.

Land Surface Temperature (LST) and Evapotranspiration (ETP)
We assessed LST and ETP from May to September, the months in which cooler surface temperatures and enhanced transpiration are most critical for both yield resilience and climate mitigation/adaptation in European agroecosystems. We chose to exclude the winter and early spring months, as regenerating farming systems often exhibit different temperature dynamics during colder periods (e.g., warmer surface temperatures due to wind

137 AgriCircle currently operates in over 5 different government programs, on all 5 continents, over 20 cash crops and more than 250.000 ha. AgriCricle has published several peer reviewed studies with major science partners like ETH Zurich, INRAe
and Thünen Institut. Introducing new concept of soil pattern detection together with ETH Zürich, Agroscope and LUFA (LINK), Publication on the process with leading German speaking soil scientists from JKI and Agroscope (LINK), VERRA announcement of our work on soil sampling that is going to be used in Development of Verra VM0042 for carbon sequestration in agriculture together with INRAe, South Pole, FiBL, Aberdeen and SGS (LINK), Co-leading the carbon modelling part (WPS 1,2,4) for ClieNfarms (LINK)

protection and vegetative cover), which could introduce bias[138]. Assessments in other climatic regions or with different growing seasons should adjust this temporal window accordingly.

A known limitation of our LST dataset is the 10:00 AM overpass time of Landsat satellites. Since temperature peaks driven by solar heating and re-radiation typically occur in the afternoon, this sampling time biases the results in favour of conventional systems, which may appear cooler than they would under a full diurnal assessment. As a result, the observed LST differences likely underestimate the actual cooling effect of pioneer farms due to evapotranspiration, especially in Southern European countries, where bare soils bake under the summer sun.

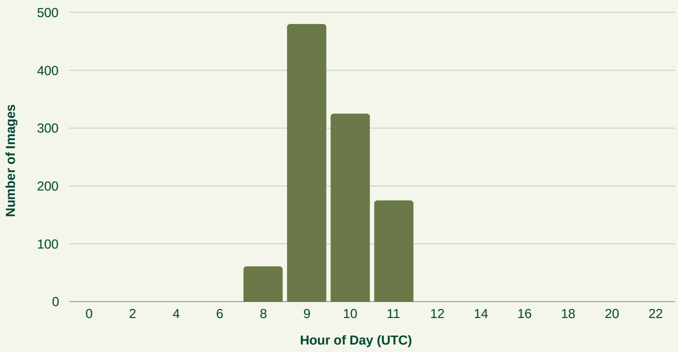


Figure 18: Distribution of Landsat (for LST) image capture time by hour

The methodology incorporates atmospheric water vapour data from the NCEP/NCAR reanalysis and has been validated against in-situ measurements across multiple stations. The validation showed an overall accuracy between -0.1 K and +0.5 K, with Root Mean Square Error (RMSE) values between 1.9 K and 2.1 K, depending on the Landsat satellite used.
A further critical limitation is the 30-metre resolution of the LST and ETP imagery in this initial phase of the study. As a result, the outputs are sufficient only to detect non-statistically significant trends. On average, pioneer fields were found to be 0.3°C cooler during the summer and exhibited 5.3 mm greater evapotranspiration.

138 Schroeder-Georgi, T., Eisenhauer, N., Herz, K., Lajoie, G., Lange, M., Scherber, C., … & Schmid, B. (2023). Plant diversity stabilises soil temperatures. Nature Geoscience, 16, 979–984. (LINK)

Due to financial constraints, we were unable to access higher-resolution commercial satellite data for this phase. We intend to address this in Phase 2 of the study. Recent advances in thermal-infrared (TIR) remote sensing are rapidly improving the availability and resolution of LST data. Commercial missions such as SatVu's HotSat-1, constellr's SkyBee-1 / HiVE, and Hydrosat's VanZyl-1 are already collecting early-afternoon imagery at spatial resolutions of 3 to 60 metres and revisit rates from hourly to every few days.

Moreover, upcoming public missions, including ECOSTRESS, TRISHNA, Copernicus LSTM and NASA SBG-TIR, are expected to provide free, science-grade TIR data from 2026 to 2030, substantially improving opportunities for more accurate and equitable remote sensing assessments of agroecological performance.

Plant Diversity
The study assessed spatial heterogeneity but not yet temporal heterogeneity. That can be integrated and is also supported by literature[139]. Temporal NDVI metrics capture the year-to-year stability of vegetation cover, which reflects management intensity. Fields under intensive management or frequent crop rotation tend to show large interannual NDVI fluctuations, whereas perennial or low-input systems maintain more stable NDVI. However, the researchers in this study were careful as the literature has not yet sufficiently assessed if that can also introduce a bias for continuous intensive non-diverse biomass cropping and/or against adaptive multi-paddock, holistic or rational grazing in grasslands. It was hence decided not to take temporal variation into account for now. Also with integrating temporal variation, further trials and data must underpin better plant diversity assessments.

Strategic result-based indicators
Whereas the general feasibility and importance of a new innovative leap in agricultural and environmental policy-making has been established by this study, the authors caution against a non-context-specific application of the strategic result-based indicators. Local, regional and national government entities already have great remote-sensing capacities within their ranks. Before designing policies, data must be systematically collected, made transparent and discussed with pioneering farmers. The operationalization must be executed with pedoclimatic and land use categoric realities and farmer-led decision-making present. Differences in altitude and inclination of assessed farmland must be taken into account for fairness. Targeted testing on agroforestry, and diverse holistically managed pastures vs intensive ones with the indicators will further improve their specific programming, robustness, fairness and effectiveness.

139 Abdi et al. (2021). Biodiversity decline with increasing crop productivity in agricultural fields revealed by satellite remote sensing. Ecological Indicators, 131, 108098. (LINK)

4.8 RFP calculations

The authors understand the RFP calculations and results presented in this study as a first version. Apart from the missing data and the continuously improvable retrofitting described above, the metric calculation can be further improved. At this stage of the analysis, the RFP metric was calculated at the country level by averaging individual farmer responses for each indicator, such as fuel use, soil cover, photosynthetic activity and others, within each country. These averaged indicator values were then combined to produce a single RFP value per country. While this method offers a practical overview of national-level trends, it does not fully capture the variability and heterogeneity of individual farm performance. A more statistically robust and representative approach involves calculating RFP at the individual farm level, by integrating each farmer‘s complete set of indicators, and then averaging these farm-level RFP values to obtain a country-level measure. This method preserves the integrity of within-country variation and avoids potential distortions caused by averaging each indicator independently before combining them. These limitations will be addressed in the next phase of the project, which will allow for the calculation of individualised RFP scores. This refinement will not only strengthen the analytical rigour of this work, but will also fulfil the commitment to participating farmers by providing them with farm-specific insights derived from their contribution to the study.

Aside from this, the current averaging approach could theoretically reward isolated high values while penalizing balanced, incremental improvements, contradicting the RFP's intended purpose. This is something the current data has not shown. Future refinement of the metric may be necessary, particularly through the use of indicator weighting or alternative aggregation methods, such as the use of standardized index scores rather than simple percentage differences, and moving beyond a flat average to a more sophisticated mathematical formulation in triangulation with ever more data, to ensure RFP is self-regenerating and ever more accurately reflecting the multidimensional nature of the full productivity of regenerating forms of agriculture.

4.9 Hazards and Biodiversity

As part of the survey amongst pioneering farmers, their hazard conditions in the years 2021-2023 were collected, as well as their personal perception of the increase of biodiversity on their fields since their adoptions of regenerating forms of agriculture. The results are displayed in table 7 and show just how frequent hazard events are becoming in agriculture, as well as how significantly and rapidly biodiversity can be supported through farming with nature.

Country	Affected by hazard 2021 (%)	Affected by hazard 2022 (%)	Affected by hazard 2023 (%)	Increased Biodiversity (%)
Belgium	40	0	20	**100**
Estonia	50	50	100	**100**
Finland	40	10	30	**83**
France	21	29	7	**100**
Germany	33	33	8	**96**
Greece	36	45	91	**94**
Hungary	0	100	0	**100**
Italy	14	43	29	**90**
Netherlands	50	0	0	**100**
Norway	0	0	33	**100**
Portugal	0	50	50	**100**
Slovenia	20	80	40	**75**
Spain	22	22	22	**100**
Sweden	0	0	0	**100**
Total	27	31	31	**94**

Table 7: Pioneer hazard conditions and biodiversity

"Together with the farmer-led association EARA we have conducted a study that embraces a new look towards agroecosystems, searching for innovative ways to stimulate rural areas and secure food security and climate adaptation by focusing on soil regeneration and biodiversity boosting."

Dr. Daniel Sacristan, Associate Professor at the University of Valencia and researcher in this study

"The EARA study shows that Regenerative Agriculture, correctly implemented, is more than a buzzword and fashion. Instead it is a pathway towards an agriculture which can feed the world and be at the same time sustainable in all three dimensions - social, environmental and economic. And this can also be verified in a transparent way, as the study further shows."

Dr. Theodor Friedrich, retired Ambassador of the FAO and independent reviewer of the study

5 Call to Action: Regenerating Full Productivity

5 Call to Action: Regenerating Full Productivity

Regenerating the Earth's and Europe's full productivity is neither an unachievable utopia nor a process on biblical time scales. Farmers are doing it today, not only without targeted support, but even against all odds.

They already produce what was and often still is believed to be impossible:

→**Higher full productivity:** Across all sites, regenerating farmers delivered 33% higher RFP on average, with gains ranging from 13% to 52%.

→**Agroecological advantage:** Compared to neighbouring fields, regenerating farms achieved over 25% higher photosynthesis, 24% higher soil cover and 16% higher plant diversity from the period between 2019–2024. This advantage means more biodiversity and better soil health.

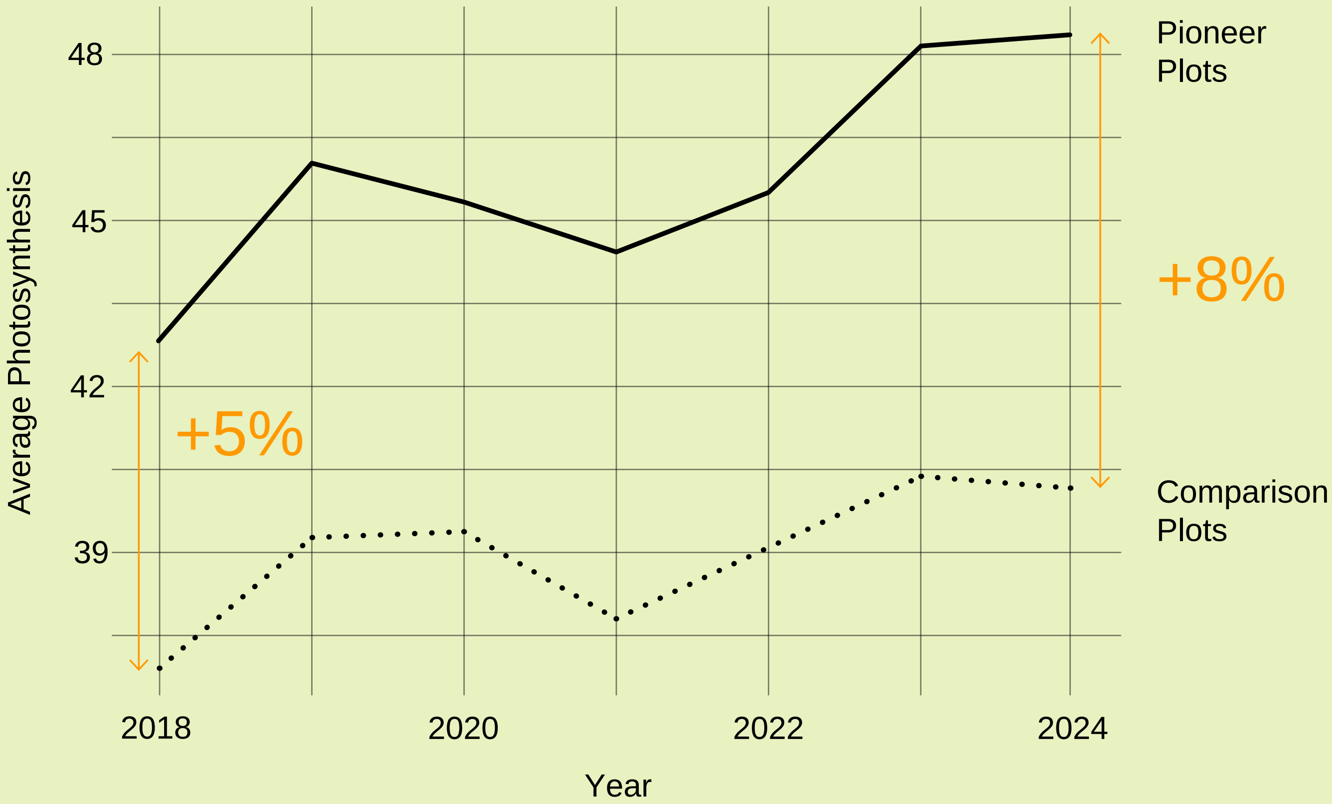
→**Yield parity with major gross margin and input improvement:** Regenerating farms achieved, on average, only a 2% lower yield (in kilocalories and protein), while using 61% less synthetic nitrogen fertiliser and 75% less pesticides and making 20% higher gross margin per hectar.

→**Regional food sovereignty:** While average EU farms import over 30% of livestock feed from outside the EU, pioneering farmers achieved similar yields using feed exclusively from within Europe.

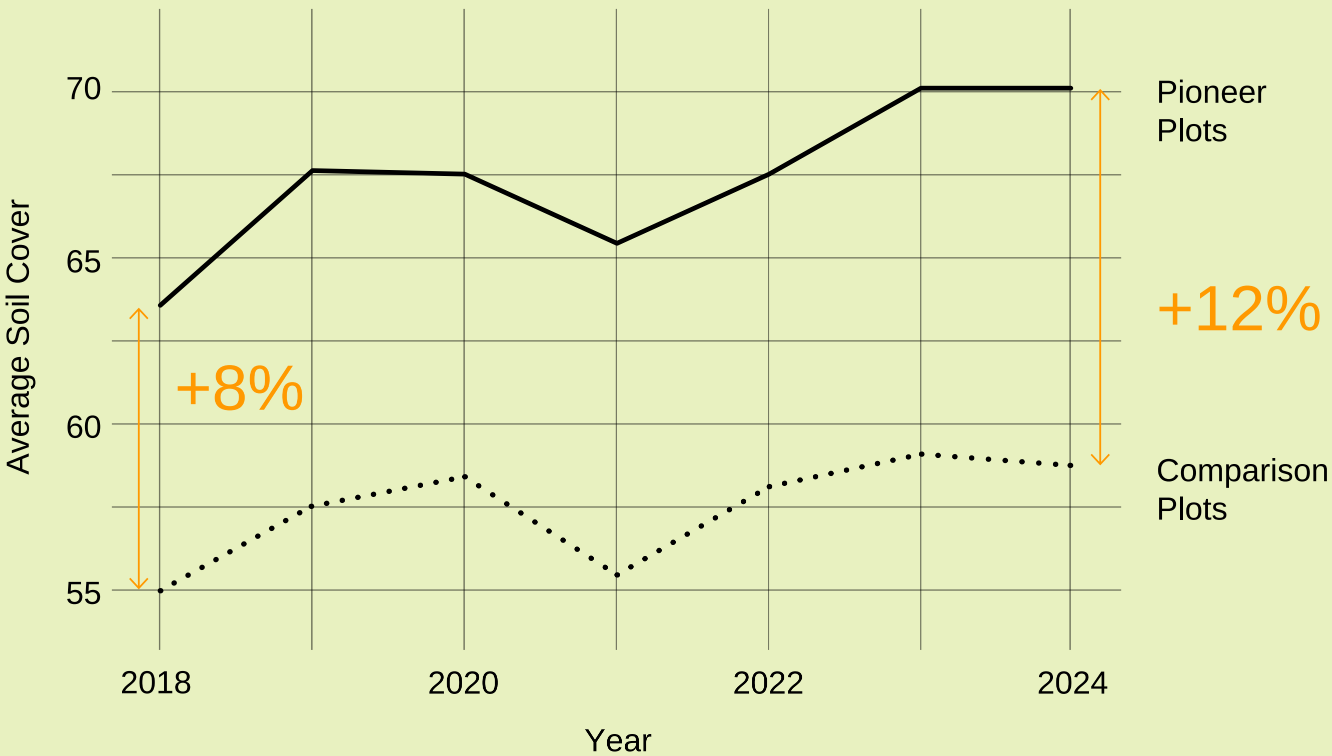
Resilience
Whereas pioneers significantly improved their whole-year photosynthesis, while already at a much higher absolute and drastically reducing nitrogen fertilization, the comparison farmers did not significantly improve their whole-year plant productivity over the last years. The same is valid for soil cover.

Next page:
Figure 19: Year over year photosynthesis and soil cover development of pioneer and comparison plots

Year-over-year Photosynthesis Gains



Year-over-year Soil Cover



Climate

Critically, for climate mitigation, their fields recorded average surface temperatures over 0.3°C cooler during summer months than surrounding agroecosystems, although since data was taken by satellites at 10:00 AM, this difference will logically be much higher in the hottest hours of the day. As described in the discussion chapter above, our next research phase will make more accurate measurements.

We assume conservative estimates for climate mitigation based on literature[140] and experiences AgriCircle has been collecting in collaboration with INRAe, Thuenen Institut, the CoolFarm Tool, Verra and others to gain critical insight into GHG balance developments during transitions[141].

We know from newest literature how transitions unfold in the first years when intensive arable crop farmers adopt feasible new practices as entry to regenerating forms of agriculture.

We conservatively and roughly estimate that, in the first years of transition, conventional farmers adopting biological intensification, input reduction and soil conservation practices can mitigate 2 t CO_2e and sequester 1 t CO_2e per hectare and year. Such results are achievable for all farmers in the first years, if supported by feasible enabling frameworks (described in detail in the next chapter).

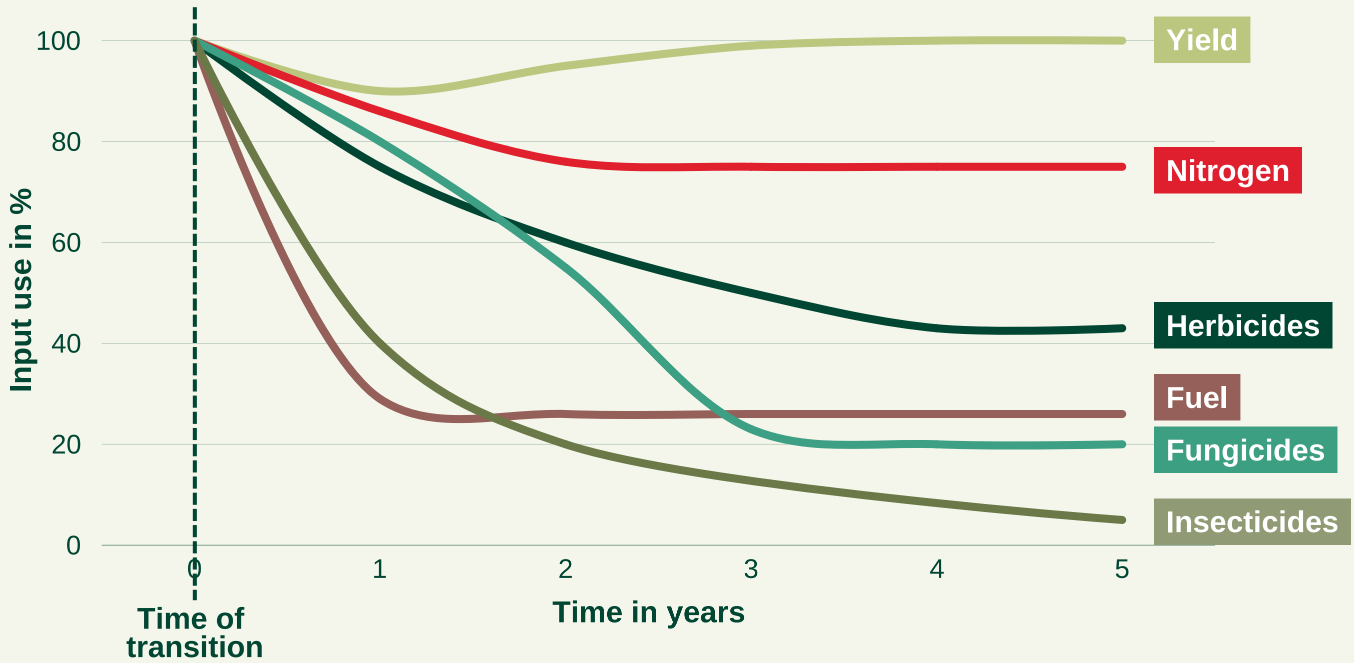


Figure 20: Typical initial transition phase results for conventional arable cropping to more regenerating forms of agriculture (excluding biological fertilization strategies or deep soil loosening)[142]

140 Freitag, M., Friedrich, T. and Kassam, A. (2024) The carbon footprint of Conservation Agriculture. International Journal of Agricultural Sustainability. ISSN 1747-762X doi: (LINK)
141 Yuzugullu et al. (2020). Understanding fields by remote sensing: Soil zoning and property mapping. Remote Sensing, 12(7), 1116. (LINK);
Yuzugulluet al. (2024). Satellite-based soil organic carbon mapping on European soils using available datasets and support sampling. Science of Remote Sensing, 9, 100118 (LINK);
VERRA announcement of our work on soil sampling that is going to be used in Development of Verra VM0042 for carbon sequestration in agriculture together with INRAe, South Pole, FiBL, Aberdeen and SGS (LINK);
Co-leading the carbon modelling part (WPS 1,2,4) for ClieNfarms (LINK)
142 Meister et al. (2025). Gesündere Böden, geringere Kosten, nachhaltige Erträge: Wie Konservierende Landwirtschaft Vorteile erntet. NABU, GKB, HSWT. (LINK)

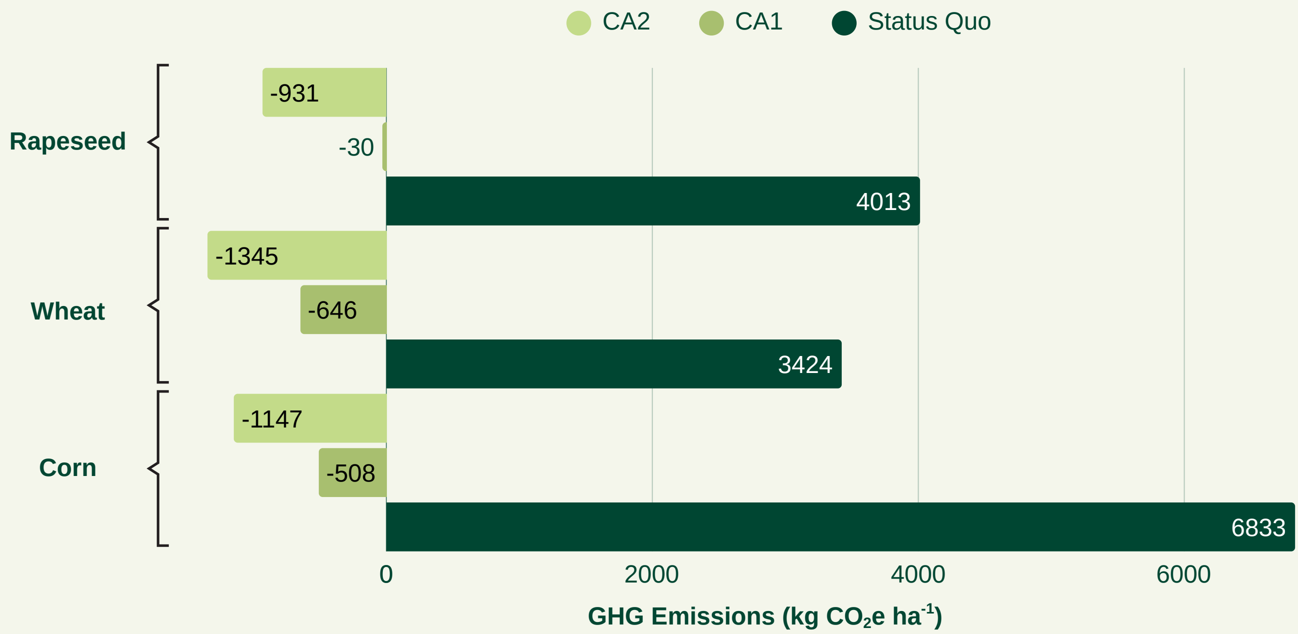


Figure 21: Different GHG balance of intensive arable cropping in Germany between the status quo (heavy tillage and synthetic inputs) and Conservation Agriculture as feasable entry to regenerating forms of agriculture (maximally reduced soil disturbance, intensive cover crops and wide crop rotations)[143]

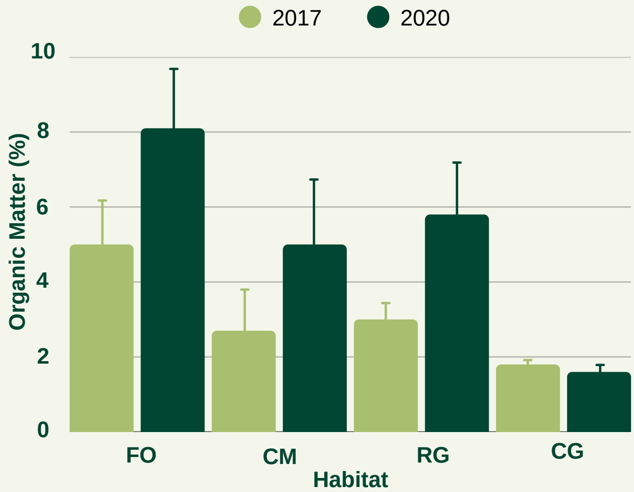


Figure 22: Changes in the % of soil organic matter between the beginning of the application of the Polyfarming system (an organic regenerating form of agriculture) in 2017 and three years later in 2020 (forest (FO), cow meadow (CM), regenerative garden (RG) and conventional garden (CG).[144]

143 Freitag, M., Friedrich, T. and Kassam, A. (2024) The carbon footprint of Conservation Agriculture. International Journal of Agricultural Sustainability. ISSN 1747-762X (LINK)
144 European Commission. LIFE programme: Manual for the design and implementation of a regenerative agri-food model: the Polyfarming system (LINK)

The EU agricultural sector emits approximately 378 million metric tons (Mt) of CO_2e annually[145]. Transitioning to regenerating forms of agriculture (biological intensification, input reduction, soil conservation) offers a promising mitigation pathway.

Assumptions:

- Each hectare adopting such practices could mitigate (reduce and sequester) 3 t CO_2e/year.
- Total Utilised Agricultural Area (UAA) in the EU: 171 million hectares.

Key Insights:

- Even a 75% adoption of regenerating forms of agriculture could more than offset current EU agricultural emissions.
- Full adoption could render the sector net carbon negative by over 1.3x its current emissions.
- This underscores the high mitigation potential of regenerating transitions, provided enabling transition frameworks are in place.

We hold that the observed results, making empirically visible the ongoing leap in the agricultural innovations of regenerating full productivity, are generally valid far beyond Europe, and proven by indigenous and pioneering regenerating land stewards throughout the world[146].

145 European Commission. (2023). Agriculture and forestry: Greenhouse gas emissions. Retrieved May 29, 2025, (LINK)
146 Montgomery et al. (2022). Soil health and nutrient density: Preliminary comparison of regenerative and conventional farming. PeerJ, 10, e12848. (LINK)
Soil Health Institute. (2021). US farms study shows positive impact of soil health management systems. (LINK);
Mazvimavi, K. (2017). Enhancing yields and climate resilience through conservation agriculture: Multi-year regional on-farm trials in Zambia. Plant and Soil. (LINK);
Muchabi, M., et al. (2014). Long-term effects of conservation agriculture on soil properties and crop yields in Zambia. Field Crops Research, 155, 1–10. (LINK);
Li, X., et al. (2020). Impact of regenerative practices on soil health in China. Soil and Tillage Research, 199, 104585. (LINK);
Sharma, S., et al. (2021). Effects of agroecological practices on crop yields in India. Agriculture, Ecosystems & Environment, 306, 107213. (LINK)

Strategic result-based indicators of RFP
As shown in our RFP influence test in 3.4., the study proves how the strategic result-based remote-sensed indicators of context-specific whole-year photosynthesis and soil cover, show a consistent and significant influence with RFP of 41% at country level. This study systematically demonstrates the potential of farmer-led innovations to enhance the regenerative capacity of agricultural systems, despite challenging conditions. The findings also provide evidence that with well-targeted public and private support, these outcomes can be scaled, improving prospects not only for farmers but for global agri-food systems generally.

Adoption Level	Area (M ha)	Mitigation (Mt CO_2e/year)	% of Sector Emissions Offset
75%	128	256.5	102%
100%	171	513	136%

Table 8. Overview of adoption scenarios for EU climate mitigation by regenerating forms of agriculture

"At last, we have the hard data from real farms that show that regeneration is not only working, but that it has a strong business case behind it. It is not only possible, but vital, to transition the European agri-food sector to regeneration as quickly as contexts allow, to ensure resilience in rural areas and food security alike. Thanks to the work of our pioneering farmers, the future of agriculture in Europe is truly bright, and we're here to offer a helping hand to our fellow farmers, to share our knowledge and experience to make the regenerative transition as smooth as possible."

Meghan Sapp, EARA Founding Farmer and Advocacy & External Relations Director

5.1 Public-Private Transition Frameworks based on tiered use of RFP

Most of the pioneers in this study are outstanding innovators. They have co-created the methodological and technological innovations that enable their productivity leap. Like many innovators and entrepreneurs, most went through significant hardship and years of development to reach this point. Fortunately, once the methods and technologies of a new epoch are established, the adoption for others becomes increasingly accessible.

Such transitions towards regenerating forms of farming are not determined by aspects like farm size or ownership type. Instead, farms achieve higher RFP per UAA where their socio-economic incentives for diversification and biological-intensification are greatest, which is mostly determined by long-term land access and security. This socio-economic aspect is to be further assessed in the second part of the research project's survey.

5.1.1 How to regulate and incentivize Regenerating Full Productivity through private and public collaboration from the local to the global level, and vice versa

In order to effectively regulate and incentivise RFP of agricultural systems, it is beneficial to differentiate the MMRV into a tiered application adaptable to any farm, biodistrict and nation.

Tier 1
The most cost-efficient tier, i.e. the strategic RFP result proxies that are whole-year photosynthesis and soil cover, can be measured at low cost and short intervals.

Tier 2
Outcomes whose measurement involves higher cost, longer intervals and higher robustness (like soil health) should be specifically programmed into policy, supply chain or insurance schemes.

Data collection on RFP via MMRV on farms should always generate value for both on and off-farm needs. Differentiation into tiers allows a significant reduction in the burden and cost of transitioning, by enabling different stackable incentivization options and thus inoculating the acceleration towards regenerating forms of agriculture. Creating a shared knowledge space would allow farmers to readily see the effects (both immediate and long-term) of changing their practices, while having access to the results and outcomes of other farmers that choose to share them.

This study outlines key context-specific result indicators that measure and manage the transition towards regenerating agricultural systems. These indicators could be monitored annually at close to zero marginal cost, and are measured as:

Tier 1
Remote-sensed indicators

- Whole year photosynthesis
- Whole year soil cover
- Optionally and to be further developed: LST, ETP, NDVI STD

Tier 1.1
Farmer reported or automatically retrieved indicators from tax records (per hectare or unit of stocked or sold output)

- Yields of plants and animals (with MJ, NPK content)
- Fuel (l)
- Energy (Mw)
- Water (m3)
- Nutrients (kg NPK, Mineral and organic fertilizers purchased or sold)
- Crop protection (€ or g/l active substance)
- Animal load (LSU)

Similarly, we have identified key context-specific **outcome indicators** to measure and manage the transition. The measurement of the outcome indicators would occur following a full crop rotation - or at least once every four years - and involve positive marginal costs through diffusing the technological innovations around precision soil mapping[147].

Tier 2
In-situ precision soil tests that measure

- SOC%
- Bulk density
- pH
- Optionally: P, more macro and micronutrients
- Optionally: Soil biodiversity

Performance indicators
Finally, we use key context-specific performance indicators (RFP KPIs) to strategically and holistically measure, regulate and incentivize the transition.

Tier 1

- **Annually (or quarterly) remote-sensed result RFP KPIs**
  - KPI 1: Absolute whole year photosynthesis in a specific pedoclimatic

147 New generations of precision soil testing methodologies allow for relatively less soil samples while increasing resolution and robustness of results, enabling a.o. reduction of inputs and soil testing costs. (Source, UK Example, Exemplary Service Provider AgriCircle)

region and land use category
KPI 2: Absolute whole year soil cover in a specific pedoclimatic region and land use category
KPI 3: Relative year-on-year change of whole year photosynthesis in a specific pedoclimatic region and land use category
KPI 4: Relative year-on-year change of whole year soil cover in a specific pedoclimatic region and land use category

Additional KPIs according to satellite data availability and innovation

Tier 1.1.

Annually reported or retrieved result RFP KPIs
KPI 5: Relative year-on-year change of purchased inputs
KPI 6: Relative year-on-year change of stocked or sold yields

Tier 2

Multi-annually in-situ precision tested outcome RFP KPIs (per hectare)
KPI 7: Absolute total soil organic carbon (SOC% and bulk density measurement)
KPI 8: Relative year over year change of total soil organic carbon (SOC% and bulk density measurement)

5.1.2 How the EU can leap-frog the agri-food system's Regenerating Full Productivity: Public-Private Transition Framework

All of the following public and private levers can work coherently and synergistically optimizing cost-effectiveness - only if they are underpinned by a shared data language and infrastructure (RFP KPIs).

Farmers need meaningful regulatory simplification, and the use of a harmonised data infrastructure will help to achieve this. This data will also inform performance-based incentives, financial and investment instruments, and tailored agronomic advice for farmers.These combined factors will foster improved farmer livelihoods, bioeconomic productivity and ecosystem and human health.

Using a harmonised data language (RFP KPIs) allows for a blended and stacked strategic approach to a complementary public-private transition framework co-enabling the regenerating full productivity of all farms in the EU.

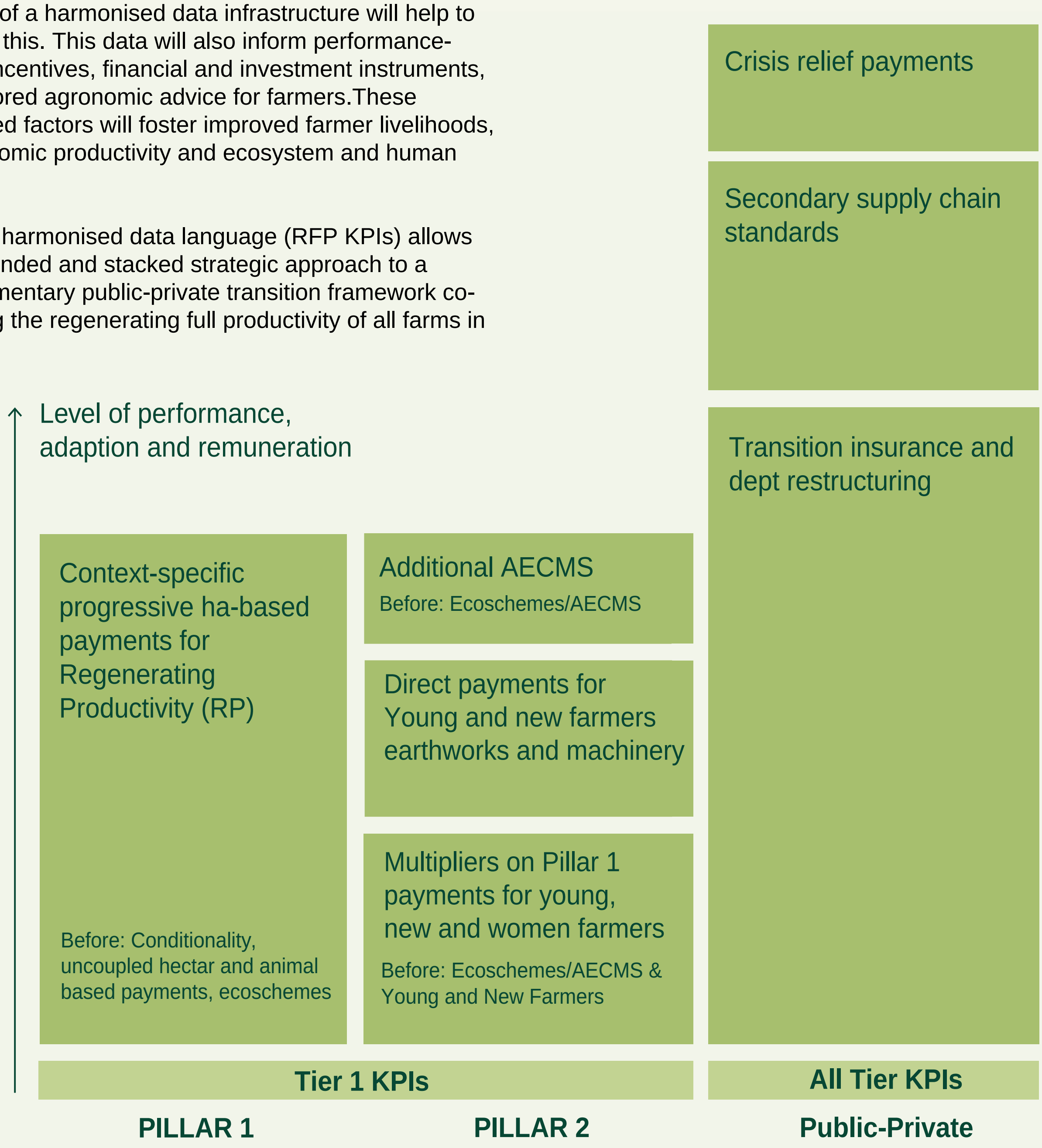


Figure 23: Harmonized public-private transition framework for enabling regenerating full productivity of agriculture

Couple CAP Pillar I[148] based payments to RFP remote-sensed result KPIs
Farmer remuneration would be linked to the performance of photosynthesis and soil cover, annually measured per hectare, rewarding for photosynthesis and soil cover both in absolute and year-on-year (YoY) performance. These results would be benchmarked against other plots from the same pedoclimatic region and land use category. These incentives should be progressive based on total farm size, with per-hectare performance-based payments adapted to the farm size distribution specific to the context of each Member State.

Couple CAP Pillar II[149] based payments to RFP remote-sensed result KPIs
Aiming for simplicity for both bureaucracies and farmers, multipliers could be paid to young farmers and new entrants on the per-hectare performance-based payment, according to the farm size distribution specific to each Member State. New entrants and young farmers could get a multiplier of >5 (with the possibility of Member-state intervention, depending on the demographic situation in each state) for the first 5 or 10 years. The longer-term commitments associated with the support framework would mitigate the problem of new entrants exiting after only 2 or 3 years.

CAP Strategic Plans
Member States must carry out impact assessments of regulations and policies, particularly for the Strategic Plans under the CAP. In our view, Member State reporting should not focus on disconnected results (such as euros per hectare under abstract categories), but on actual results: the economic, ecological and social impact of the actions taken. The RFP serves that purpose, providing a solid, holistic approach that not only complies with CAP objectives, but also delivers tangible improvements in soil health, biodiversity and rural livelihoods by rewarding year-on-year improvement.

CSRD, CSDD, SMRL, WFRD, LULUCF, EU Taxonomy, EUDR, possible Agri-ETS and Benchmarking
All of the aforementioned policy projects will use either assumptions or their own methodologies to assess the performance of land use management in some way.To ensure consistency, robustness and cost-efficiency, we propose that these initiatives adopt a shared set of result-based indicators: the Regenerating Full Productivity (RFP) KPIs. Designed for high resolution and practical use, the RFP KPIs would enable policy coherence across directives, reduce duplication of data collection and lighten the reporting burden on land managers. We recommend that the European Commission integrate RFP KPIs and a harmonised MMRV (Monitoring, Measurement, Reporting and Verification) framework as the common reference standard across relevant legislation. For example, if a carbon tax or Agri-ETS is introduced targeting large processors and retailers under CSRD and CSDD, their land-related performance obligations could be measured through the RFP framework. This would simplify compliance, ensure environmental integrity, and align economic incentives with regenerative outcomes.

Member State Action
Member States already allocate substantial sums to farmers for hazard relief or public goods provisioning. These payments could be aligned with the RFP KPIs and translated into proactive financial instruments that facilitate the transition, rather than reactive emergency payments following environmental or economic crises. Additionally, Member States could at their own accord be enabled to co-finance the RFP KPI remuneration system outlined for Pillar I and II of the CAP above. Similarly, federal, regional and local administrations, could be encouraged to utilise their subsidies with the RFP KPI system, fostering coherence across governmental levels and increasing efficiency.

Blended Transition and Risk Finance – Investments in open EU strategic autonomy and high competitiveness
Currently neither public crisis relief payments, debt support nor crop insurance schemes offer significant incentives for adaptation. Bold, directed action is required to finance and de-risk the regenerative transition.
A comprehensive and applicable transition framework that incorporates investment support, insurances, debt reduction and restructuring mechanisms could be anchored in RFP KPIs. This framework would include clear guidance on redefining financial services for the agricultural sector, shaping how agricultural success and risks are measured and managed through adapted credit risk management/scorecards, business risk evaluation, exposure and market risk management (including stress testing and simulation).
The core of this framework is the creation of a jointly private-public financed transition insurance scheme for farmers. These insurances need to be context-specific programs, implemented in collaboration with agricultural banks, crop insurers, off-takers and administrative bodies. These groups would reimburse farmers for costs incurred from failed trials and temporary yield reductions in the first 4 years of participating in a full (Tier 1 and 2) RFP KPI MMRV guided transition program.

For the insurance to be scaled, it could be backed and leveraged by dedicated EIB action. These instruments could then be stacked with preferential interest rates on new CAPEX loans or on restructuring existing farm

148 Pillar I of the CAP currently provides direct payments and market support, including eco-schemes that reward voluntary environmental practices that go beyond baseline requirements, but fall short of regenerative outcomes. (Source)
149 Pillar II of the CAP focuses on rural development incentivising young farmers, and providing non-agricultural support to services and infrastructure. Ideally this is used to support innovation and collaboration with farmers, not detract from agriculture.

debt. Further support could come from off-takers, local water producers or administrations that are looking to accelerate their local regeneration efforts (cities, regions, etc.).
Additionally, a meaningful Agri-ETS that places the burden on the most concentrated parts of the food chain (processing and retail) could create significant funds for investing into a European transition insurance fund.

Private Sector
It would be critical that RFP KPIs continue to be incentivized, promoting the uptake in supply chain contracts as secondary standards. The current approach is uncoordinated in networks such as the SAI Platform or even within multinationals themselves. Simplicity, coherence and ever-reducing marginal costs of MMRV are the foundation of effectively scaling regenerating forms of agriculture through supply chains. By petitioning the public sector for policy coherence, regulation and future subsidies for the RFP KPIs, this could be greatly accelerated.

Access to land
Financial instruments, including preferred leasing and buying conditions, should be utilised to prioritise regenerating forms of agriculture. If farmers prove continuous improvement on RFP KPIs, they should be protected from losing rent contracts and get preferential access to rent contracts as well as rent reductions for increasing the value of the land. When land came up for sale, small, young and/or farmers with continuous improvement on RFP KPIs should get preferential treatment.

Direct investments in watershed regeneration earthworks and technology
In order to achieve systemic and structural climate mitigation and adaptation, Europe must rapidly scale nature-based blue and green water cycling mechanisms[150]. Investment support should be targeted at installing landscape features such as water retention and erosion control elements like swales, ponds, infiltration holes and others. Additionally, leading EU technology developers , e.g. in digital fencing technology, should be supported for improving livestock management. This could be additional support to complement the strategic RFP-based strategies mentioned above.
The implementation of a shared data language and infrastructure based on RFP KPIs presents a transformative opportunity for both public and private stakeholders. By aligning policy instruments, financial mechanisms, regulatory frameworks and supply chain standards with RFP KPIs, we could achieve a more coherent, cost-effective and performance-driven approach to agricultural regeneration.

Harmonising data across CAP payments, regulation, strategic planning, financial instruments and supply chain incentives will not only streamline reporting burdens but also drive real economic, ecological and social impact. Such an integrated approach would foster regenerative approaches, enhance farmer resilience and strengthen Europe‘s bioeconomy, competitiveness, strategic autonomy, cohesion and health.

150 BioEast & Soil Water Nexus (LINK)

5.2 Ongoing and next steps

Regenerating Europe Tour

With the Regenerating Europe Tour, EARA is taking the “Call to Action: Comprehensive EU AgriFood Policy Programme” around Europe over 2 years leading up to 2027. The Tour is a strategic initiative to foster collaboration across Europe’s agrifood system, aiming to create a new ‘social contract’ for partnerships among farmers, public servants, policymakers, industry, civil society and science. Focused on ecological, social and economic regeneration, the tour seeks to foster the shift from degradation to regeneration. On the road we will visit 15+ European capitals over the next two years, with regular touchpoints in Brussels, highlighting existing work, necessary actions and innovations for large-scale grassroots transition - in particular everything related to EARA’s proposed Public-Private Transition Framework described above. The tour started off with the Agrifood Regeneration Week in Brussels in February 2025 and will continue across EU Member States, hosting strategic dialogues and diverse events to drive systemic change in agriculture and food systems.

Impact assessment model exercises and other uses

The epistemological and methodological foundations of this study - and the subsequent data collection - were designed to align with other major crop, biomass and trade models such as GlobeBiom, CAPRI and Magnat, among others.

Current impact assessments such as the EU CAP SP Climate Impact assessment can be massively improved in robustness, resolution and use value.

Over the next months, the results and data of this research will be fed by IIACS and the LAMASUS project into an EU-wide impact assessment through the GlobeBiom model. We hope to advance on that frontier to also assess regional NUT2 level impact via CAPRI and international trade impact potentials via Magnat.

The work of Regenerating Full Productivity, from data collection methods to analysis, is critical to advance standard data collection tools and methods such as in LPIS, GSA, FADN, Agri Sustainability Compass or the JRC Farm Records, in the interest of innovation, simplification and farmer agency.

Member State pilots and European Mutual Consultation Group on Result-based AgriFood Policy

EARA is working tirelessly alongside prominent and impressive regional, national and private sector initiatives like BalticSeaAction Group, RegenNL, PAVD, BioEastHub, SAI and many others. This collaboration seeks to make meaningful data harmonisation a reality to benefit farmers, businesses, citizens and ecosystems, while starting with a strategic result-based program for example in eco-schemes before 2027.

In the same workstream, EARA is hosting farmer-led mutual consultation meetings with pioneering civil servants and selected experts from around Europe to discuss a strategic result-based agrifood policy. The group is chaired by three former agricultural ministers in the EU from France, the Netherlands and Slovakia. The aim is to jointly understand, critique, improve, appreciate and support strategic result-based coupling of area-based direct payments and innovation fostering agricultural benchmarking in the EU.

Research Project Phase 2

Harvesting learnings and advances from all of the above, Phase 2 of our research will scale and refine the Regenerating Full Productivity (RFP) framework in both scope and depth. We will expand farmer data collection and integrate metrics such as nutrient density to evaluate impacts on public and animal health in a practical, meaningful way. Our goal is to develop a low-cost, context-sensitive predictive model for assessing land use performance annually. We will also productise results-based indicators and spectral data for use in financial sectors—supporting credit risk, business risk and market assessments—as well as for farmer-focused instruments like preferential loans, debt restructuring and transition insurance. All developments will remain farmer-led, prioritising local agency and data sovereignty, and supporting the regeneration of biocultural diversity.

Closing words

If the efforts and resources of both the public and private sectors were redirected from conflict driven by geopolitical competition toward fostering worldviews rooted in integration and cooperation, societies could adopt more constructive approaches to addressing environmental, social, and political challenges. The binary framing of ‚us‘ versus ‚other‘ would be reconsidered in light of a shared human condition. Recognizing that all people are part of a common global community reinforces the understanding that humanity is embedded within, and inseparable from, the natural world. In this context, human agency can be viewed not as separate from nature, but as a potential expression of nature‘s capacity for reflection and intentional action striving for harmony and syntropy.

In an act of cultural solidarity and appreciation, not appropriation, we share here the words of Valiana Akejandra Aguilar Hernández, Co-Founder Suumil Móokt'áan Collective, Mayan farmer and beekeeper:

„Healing our soils means healing our history, our present and our future."

Appendix

In this Appendix we will dive deeper into the science, technology and data that this study is built upon, to make its reasoning more transparent and thus open to constructive criticism.

The Appendix has three parts:

1. Expanding on the themes of photosynthesis, health and remote-sensing
2. Deeper reflection on related works
3. Nationally-compounded pioneer data, Eurostat benchmarking data, retrofitting details and survey

1 Expanding on the themes of photosynthesis, health and remote-sensing

It is often assumed that incentivizing photosynthesis and NPP would have negative side-effects on biodiversity and possibly health. We address these assumptions before discussing in more detail this study's remote-sensing set-up, as well as future possibilities.

Introduction to NPP, biodiversity and health

Photosynthesis in symbioses with soil (or ocean) microbiomes is the foundation of plant life, converting light energy into chemical energy, primarily in the form of glucose. This energy fuels metabolic activities that produce carbohydrates, proteins, lipids and secondary metabolites, all of which are crucial for plant, animal and human growth and health. Increased NPP, photosynthetic efficiency and completion are the central drivers of numerous plant benefits, including enhanced pest resistance, improved yields, better soil health and the creation of a more beneficial soil microbiome. These processes are interconnected and often driven by the plant's ability to efficiently photosynthesize, thus producing more energy, which can be shared with soil organisms and lead to overall plant and soil health improvements.

Photosynthesis as the Primary Driver for Plant Health and Yield
Research has found that photosynthesis is a crucial determinant of plant growth and productivity. Efficient photosynthesis enables the plant to produce more sugars and other organic compounds, which are used for growth and reproduction. These compounds, often referred to as „liquid carbon," are released into the soil, benefiting the soil microbiome[151]. Increased photosynthesis directly contributes to higher crop yields by providing the plant with more energy to support cellular functions and metabolic processes. Increased photosynthetic activity enhances nutrient uptake and assimilation, especially for essential elements like nitrogen and phosphorus, which are critical for healthy plant development and improved crop productivity[152].

NPP, Biodiversity & Toxicity
Net Primary Productivity (NPP) and photosynthesis proxy measurements function as a crucial holistic indicator of ecosystem health, integrating photosynthesis efficiency, biodiversity and soil health potential. Increased photosynthesis and greater photosynthetic efficiency enhance biomass production and are the foundation of diverse and resilient ecosystems. Research has shown that higher NPP is linked to improved soil health in the EU (probably also beyond, but the study assesses only the EU), reinforcing the role of productive landscapes in maintaining ecological regenerating capacity[153].

Additionally, native-dominated plant communities often outperform invasive species and monocultures in NPP, suggesting that biodiversity promotes greater productivity and vice versa[154]. Structural diversity, such as grassland height heterogeneity, further supports pollinator diversity, highlighting the interconnectedness of ecosystem functions[155]. However, environmental degradation, as well as exhaustion, overfertilisation and contamination such as microplastic pollution, disrupts these processes by reducing photosynthesis rates, ultimately lowering NPP and weakening ecosystem stability[156]. Given these dynamics, NPP and photosynthesis proxies serve as a powerful meta-indicator, capturing the interplay between productivity, biodiversity and environmental stressors in shaping ecosystem health.

Photosynthesis and Pest Resistance
A key advantage of enhanced photosynthesis is that, in co-evolution with regenerating soil health and microbiomes, it boosts plant resistance to pests and diseases. More energy produced through photosynthesis allows plants to allocate resources to defense mechanisms, including the production of secondary metabolites[157]. These metabolites often act as natural pesticides. Additionally, more photosynthate can be used to enhance the plant's immune system,

151 Chauhan et al., (2023). Soil microbiome: Diversity, benefits and inateractions with plants. Sustainability, 15(19), 14643. (LINK)
152 Zhu et al., (2025). A global estimate of multiecosystem photosynthesis losses under micro-plastic pollution. Proceedings of the National Academy of Sciences, 122(11), e2423957122.. (LINK)
153 Romero et al., (2024). Soil health is associated with higher primary productivity across Europe. Nature ecology & evolution, 8(10), 1847-1855. (LINK)
154 Wilsey et al., (2024). Biodiversity: Net primary productivity relationships are eliminated by invasive species dominance. Ecology letters, 27(1), e14342. (LINK)
155 Müller et al. (2023). Grassland vertical height heterogeneity predicts flower and bee diversi-ty: an UAV photogrammetric approach. Scientific Reports. (LINK)
156 Zhang et al. (2024).
157 Martinez, E., Lopez, S., & Sanchez, R. (2022).

increasing its ability to resist pest attacks[158]. This relationship demonstrates how photosynthesis serves as a foundational factor in improving plant resilience to biotic stressors. Studies have shown that plants with higher photosynthetic efficiency and healthier biomes exhibit stronger immune responses, helping them to fend off pathogen.

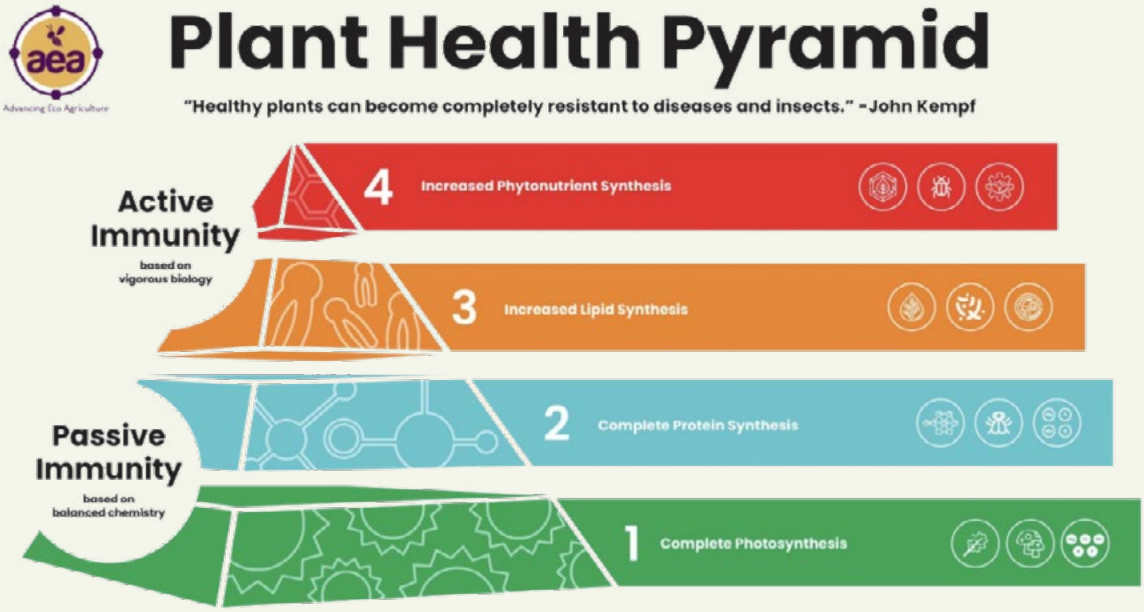


Figure 24: Plant Health Pyramid[159]

Soil Microbiome Health and Carbon Secretion
Efficient photosynthesis also drives the production of „liquid carbon", organic compounds like sugars, amino acids and other metabolites that plants exude into the soil via their roots. This carbon is a primary energy source for soil microbes[160]. By increasing photosynthetic activity, plants produce more carbon that can be shared with the soil microbiome, fostering the growth of beneficial microbes, improving soil structure and enhancing nutrient cycling. The healthier the soil microbiome, the better the plant can access the nutrients it needs and vice versa, forming a positive feedback loop that improves plant and soil health. Research has shown that soil microbial diversity, which is strongly influenced by the carbon released by plants (and of course also by many other factors such as tillage, pesticides, etc), enhances nutrient cycling, increases water retention and bolsters pest resistance through microbial-mediated plant defense mechanisms[161].

158 Zhang, Q., Zhang, Y., & Liu, P. (2023). Microbial interactions and their role in enhancing pest resistance in plants. Ecology and Evolution, 13(22), 1-15. (LINK)
159 John Kempf and Advancing Eco Agriculture. (LINK)
160 Liu, Y., Xie, C., & Zhang, D. (2024). Soil microorganisms and plant health: A critical role in improving stress resistance and growth. Frontiers in Plant Science, 15(3), 32-48. (LINK)
161 Liu, Y., Xie, C., & Zhang, D. (2024).

Increased photosynthetic efficiency, completion and thus NPP acts as a driver for a cascade of benefits: enhanced yields, improved pest resistance, healthier soil and a more robust soil microbiome. These interconnected systems work together, with photosynthesis at the core, enabling plants to thrive, protect themselves from pests and contribute to long-term soil health.

Photosynthesis, Healthy Eating and One Health
Contrary to reductionist, prescriptive dietary guidelines, we aim to grow the common understanding in the complexity and effects of healthy growing and eating. Scientist and writer Anne Biklé, co-author of "The Hidden Half of Nature", is a key reference in talking about healthy food and diets. She emphasises four fundamental aspects (FABs) of healthy eating - with a focus on fibre, phytochemicals, long-chain fats, and fermented foods[162]. The following section is dedicated to discussing how Biklé's FABs of healthy eating are proven to support metabolic health, immune resilience and chronic disease prevention. RFP is designed to be a proxy for the parts of FABs or other healthy food and eating approaches that are influenced by land use management.

162 Montgomery & Biklé (2015). The hidden half of nature: The microbial roots of life and health. W. W. Norton & Company. (LINK)

Figure 25: Four fundamental aspects of healthy eating (FABs)

Plants with improved photosynthetic performance enhance carbon fixation, leading to the production of more sugars and starches essential for plant, microbiome and human metabolisms[163]. This also improves nutrient uptake, boosting levels of essential minerals (like iron, zinc and magnesium[164]) and trace elements, and facilitates greater synthesis of bioactive compounds, including vitamins and antioxidants, which support human health[165]. These benefits manifest in higher carbohydrate quality, regulating blood sugar and reducing the risk of diabetes[166]. They also contribute to improved vitamin and mineral profiles, which can boost immune function and reduce inflammation[167], and increase secondary metabolites like flavonoids and carotenoids, combating oxidative stress and reducing chronic disease risks[168]. Of note is that the American Academy of Nutrition and Dietetics issued a first ever dietary recommendation on the consumption of flavanols, a common class of flavonoids, to reduce the risk of cardiometabolic disease[169].

Enhanced photosynthesis increases the availability of energy and nutrients within plants, driving the production of phytochemicals, bioactive compounds that play a crucial role in microbiome and human health. As plants absorb more light energy, they fix more carbon, nitrogen, and, via enhanced and active exchange with bacteria, fungi, protozoa and the larger microbiome in the soil, and produce more complex compounds. That leads to greater synthesis of flavonoids, carotenoids, glucosinolates, and polyphenols, each of which can have protective effects against chronic diseases[170]. Flavonoids reduce inflammation and improve heart health[171], carotenoids neutralise oxidative stress and lower cancer risk[172]. Glucosinolates aid in liver detoxification[173], and polyphenols help regulate blood sugar and blood pressure, reducing the risk of diabetes[174]. Additionally, plants with stronger stress resistance produce higher levels of antioxidants, further enhancing their health benefits[175] and the flavor of fruits and vegetables[176].

By improving photosynthetic performance and soil microbiomes, crops can naturally enhance their nutritional and medicinal value, offering a powerful strategy to combat non-communicable and inflammatory diseases while increasing immune-boosting compounds[177].

Plants' photosynthetic performance influences not only carbohydrate production but also lipid composition in plants, playing a crucial role in metabolic health and NCD prevention. Key plant-derived fats include omega-3 fatty acids (ALA), rich in flaxseeds, walnuts and leafy greens, which support brain health and reduce inflammation[178]. Further, omega-6 fatty acids (LA), present in seeds and nuts - which require balance with omega-3s to prevent inflammation[179] - and monounsaturated fats (MUFA), rich in avocados and olives, help lower cholesterol and heart disease risk[180]. Beyond direct plant consumption, photosynthetic performance also impacts livestock nutrition and thus human nutrition. Grass-fed livestock, consuming diverse, nutrient-rich forage, produce meat and dairy with a healthier fat profile, including higher omega-3 levels and a better omega-6 to omega-3 ratio compared to grain-fed animals[181]. They also produce richer and more diverse polyunsaturated fat profiles (with two or more carbon bonds) than plant-derived fat profiles, resulting in reduced inflammation, improved cardiovascular health and better metabolic function[182] in humans consuming grass-fed products[183]. Additionally, by upcycling plant secondary metabolites and transforming them in mammalian antioxidants,

163 Slavin, J. L. (2013). Carbohydrates, dietary fiber and resistant starch in white vegetables: links to health outcomes. Advances in nutrition, 4(3), 351S-355S. (LINK)
164 Carr, A. C., & Maggini, S. (2017). Vitamin C and immune function. Nutrients, 9(11), 1211. (LINK)
165 Aune et al. (2017). Fruit and vegetable intake and risk of chronic disease. Int. J. Epidemiology, 46(3), 1029-1056. (LINK)
166 Slavin, J. L. (2013)
167 Carr, A. C., & Maggini, S. (2017)
168 Hertog et al., (1993). Flavonoids and heart disease. The Lancet, 342(8878), 1007-1011. (LINK)
169 Crowe-White et al. (2022). Flavan-3-ols and cardiometabolic health: first ever dietary bioactive guideline. Advances in Nutrition, 13(6), 2070-2083. (LINK)
170 Aune, D., et al. (2017).
171 Hollman et al., (2011). Polyphenols and cardiovascular health. J. Nutrition, 141(5), 989S-1009S. (LINK)
172 Tan et al., (2010). Tomato-based food products for prostate cancer prevention: what have we learned?. Cancer and Metastasis Reviews, 29, 553-568. (LINK)
173 Traka, M. H., & Mithen, R. F. (2011). Plant science and human nutrition: challenges in assessing health-promoting properties of phytochemicals. The Plant Cell, 23(7), 2483-2497. (LINK)
174 Del Rio et al., Dietary (poly) phenolics in human health: structures, bioavailability, and evidence of protective effects against chronic diseases. Antioxidants & redox signaling 18.14 (2013): 1818-1892. (LINK)
175 Aune et al., 2017
176 Elshafie, H. S., Camele, I., & Mohamed, A. A. (2023). A comprehensive review on the biological, agricultural and pharmaceutical properties of secondary metabolites based-plant origin. International journal of molecular sciences, 24(4), 3266.(LINK)
177 Carr, A. C., & Maggini, S. (2017).
178 Simopoulos, A. P. (2016). An increase in the omega-6/omega-3 fatty acid ratio increases the risk for obesity. Nutrients, 8(3), 128. (LINK)
179 Simopoulos, A. P. (2016).
180 Mozaffarian, D., Micha, R., & Wallace, S. (2010). Effects on coronary heart disease of increasing polyunsaturated fat in place of saturated fat: a systematic review and meta-analysis of randomized controlled trials. PLoS medicine, 7(3), e1000252. (LINK)
181 Daley et al., (2010). A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. Nutrition journal, 9, 1-12. (LINK)
182 Simopoulos, A. P. (2016).
183 Daley et al., (2010)

grass-fed livestock also provides meat and milk higher in antioxidant levels, which can benefit shelf life and the potential healthfulness of meat and milk for consumers[184]). Importantly, livestock consuming plants that humans cannot consume can provide another, non-competitive avenue to raise phytochemical antioxidant intake in the human diet, in addition to being able to obtain compounds otherwise not readily obtained in the human diet through direct consumption of plant foods[185].

Proper fat balance, both through plant-based diets and grass-fed animal products, supports energy metabolism[186], lowers chronic inflammation and reduces the risk of obesity and heart disease.

Enhancing photosynthesis together with soil health, for which the integration of livestock in optimal management in agricultural systems is a decisive lever, can thus optimize all food sources, contributing to better plant, animal and human health, and reduced NCD prevalence. When assessing what reasonable public support efforts can be made for farmers and what dietary education is disseminated among eaters to contribute to bettering public and planetary health, this needs to be fully considered.

Remote-sensing technology fit for purpose?

Current satellites like sentinel-2, MODIS, Landsat, and others are all good sources for NPP assessments, with resolutions ranging from 250m (MODIS) to 10m (Sentinel-2), and from 16 days temporal resolutions (Landsat) to daily monitoring (MODIS)[187].
In the future, as innovators demonstrate and the scientific literature expects, continued significant comprehensive improvement is to be expected. Satellites like WorldView-3 and GeoIQ have already demonstrated resolutions down to 30 cm to 50 cm, and similar future missions will continue to push spatial resolution limits for vegetation monitoring. More upcoming missions like Landsat 10 and Copernicus Sentinel-2 Continuity are expected to keep improving spatial resolution while maintaining broad coverage[188]. With improved resolution, it will become possible to monitor smaller vegetation patches and finer-scale changes in NPP. Newer missions such as NASA's SWOT (Surface Water and Ocean Topography) and Copernicus Sentinel-4/Sentinel-5 will continue to improve temporal resolution, allowing near-daily global coverage[189].
Future satellites are likely to carry hyperspectral sensors (like NASA's DESIS or HyspIRI) with fine spectral resolution[190], which would allow for more accurate differentiation of vegetation types and conditions. These sensors can also enhance NPP modeling by providing more detailed spectral information. Multi-Sensor Approaches[191] fusing optical, radar and thermal infrared data from multiple satellites will improve assessments, enabling better differentiation between land cover types and more accurate productivity estimates in varying climate conditions.
Overall, satellite innovation is moving towards greater precision, frequency, and cross-sensor synergy, making assessments increasingly reliable and insightful for both agro environmental monitoring and policy decision-making[192].

Detailed discussion of remote-sensing analysis in this study

We discuss in more detail here only the strategic result-based RFP indicators photosynthesis and soil cover. As discussed above, photosynthesis and soil cover results were produced by the AgriPurpose product DORA. AgriPurpose is a RegenAg SaaS intelligence provider formerly known as AgriCircle[193], currently evolving into a steward-owned, purpose-driven joint venture of key farmer, industry and NGO stakeholders.
Understanding how well photosynthetic plant productivity was performing during a growing season is vital for effective regenerating farm management[194]. DORA evaluates plant performance by analyzing NDVI and RVI data over time and calculating the Area Under the Curve (AUC). This method integrates measurements throughout the season, capturing both the intensity and duration of plant growth. The resulting AUC value serves as an annual photosynthesis performance assessment proxy as NDVI reflects canopy greenness

184 Van Vliet, S., Provenza, F. D., & Kronberg, S. L. (2021). Health-promoting phytonutrients are higher in grass-fed meat and milk. Frontiers in Sustainable Food Systems, 4, 555426. (LINK)
185 Evans, N., Cloward, J., Ward, R. E., van Wietmarschen, H. A., van Eekeren, N., Kronberg, S. L., ... & van Vliet, S. (2024). Pasture-finishing of cattle in Western US rangelands improves markers of animal metabolic health and nutritional compounds in beef. Scientific Reports, 14(1), 20240. (LINK)
186 Petersen et al., (2016). Metabolic effects of dietary fat balance. Cell Metabolism, 23(3), 435-445.
187 Rodigheri et al., (2020). Net primary productivity and dry matter in soybean cultivation utilizing datas of NDVI multi-sensors. In 2020 IEEE Latin American GRSS & ISPRS Remote Sensing Conference (LAGIRS) (pp. 115-120). IEEE. (LINK)
188 Spinosa, A., Fuentes-Monjaraz, M. A., & El Serafy, G. (2023). Assessing the use of Sentinel-2 data for spatio-temporal upscaling of flux tower gross primary productivity measurements. Remote Sensing, 15(3), 562. (LINK)
189 Veefkind et al., (2012). TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications. Remote sensing of environment, 120, 70-83. (LINK)
190 Defourny et al., (2019). Near real-time agriculture monitoring at national scale at parcel resolution: Performance assessment of the Sen2-Agri automated system in various cropping systems around the world. Remote sensing of environment, 221, 551-568. (LINK)
191 Wang, Z., Liu, Z., & Huang, M. (2024). NDVI joint process-based models drive a learning ensemble model for accurately estimating cropland net primary productivity (NPP). Frontiers in Environmental Science, 11, 1304400. (LINK)
192 Almeida et al.,. (2024). Satellite-based Machine Learning modelling of Ecosystem Services indicators: A review and meta-analysis. Applied Geography, 165, 103249. (LINK)
193 AgriCircle currently operates in over 5 different government programs, on all 5 continents, over 20 cash crops and more than 250.000 ha. AgriCircle has published several peer reviewed studies with major science partners like introducing new concept of soil pattern detection together with ETH Zürich, Agroscope and LUFA (LINK);
publication on the process with leading German speaking soil scientists from JKI and Agroscope (LINK),
award for best satellite solution for agriculture from EUSPA (ESA) with DORA (LINK).
194 Huffman et al., (2015). Improving and evaluating the soil cover indicator for agricultural land in Canada. Ecological Indicators, 48, 272-281. (LINK)

and chlorophyll content, key factors in photosynthesis[195], offering a comprehensive view of crop and a partial view on ecosystem performance and productivity.

To provide a comprehensive view of soil cover throughout the year and complement the agroecosystem service assessment, DORA aggregates NVDI and RVI-based soil cover assessments from individual satellite images. By analyzing this data over time, DORA calculates the soil cover metric as the number of days the soil remains covered by vegetation annually. Before aggregating to yearly values using the AUC, DORA binarizes each scene at the pixel level (10x10 meter resolution and 0.4 threshold) to determine whether a pixel is soil-covered or not, based on vegetation signals specific to that scene. This spatio-temporal binarization is then aggregated to produce the yearly soil cover information.

NDVI Area Under Curve Error Analysis
In DORA, the yearly NDVI AUC aggregates regularly sampled NDVI observations into a single annual proxy for photosynthetic performance. Because NDVI measures chlorophyll absorption directly, high-quality optical inputs are essential, yet each processing step adds uncertainty that propagates into the AUC. Sentinel-2's radiometric calibration of the red and NIR bands contributes a 3-5% reflectance error[196]. Atmospheric correction adds uncertainty in surface-reflectance retrieval, and cloud-masking under a 35% threshold introduces 5-15% error[197]. When clouds obscure scenes for up to half the year, SAR-derived NDVI fills gaps at the cost of an additional 17% RMSE in the NDVI-RVI relationship according to our integration methodology.

Error Source	NDVI Error Range (%)
Radiometric calibration (RED/NIR)	3.Mai
Atmospheric correction (surface reflectance)	5.Okt
Cloud detection (commission & omission)	Mai.15
SAR interpolation (NDVI ← RVI)	Okt.17

Table 10: Sentinel-2 & SAR Error Ranges

Values and NDVI error ranges for each field size were derived by multiplying the border-pixel ratio - computed for square fields as: by an assumed mixed-pixel error of 20-40%.

Field Size (ha)	Shape (m × m)	Pixel Grid	Border-Pixel Ratio	NDVI Error Range (%)
0.1	~32 × 32	3 × 3	0 - 88.8%	0 - 35.5
0.2	45 × 45	4 × 4	~25 - 75%	~5 - 30
0.5	70 × 70	7 × 7	~20 - 51%	~4 - 20
1.0	100 × 100	10 × 10	~15 - 36%	~3 - 14
2.0	141 × 141	14 × 14	~10 - 26%	~2 - 10
4.0	200 × 200	20 × 20	~8 - 19%	~1.6 - 7.6
10.0	316 × 316	31.6 × 31.6	~6 - 12%	~1.2 - 4.8
20.0	447 × 447	44.7 × 44.7	~5 - 9%	~1.0 - 3.6
30.0	548 × 548	54.8 × 54.8	~4 - 7%	~0.8 - 2.8
40.0	632 × 632	63.2 × 63.2	~3.5 - 6%	~0.7 - 2.4
50.0	707 × 707	70.7 × 70.7	~3 - 5.2%	~0.6 - 2.1

Table 11: Field-Size Border-Pixel Ratios & Per-Interval NDVI Error

Discussions and Future Outlook
DORA operates as a comparative indicator, evaluating yearly photosynthesis performance and soil-cover persistence across agricultural fields by exploiting NDVI time series. Its reliance on open-access optical imagery ensures operational scalability; however, the core technical obstacle remains prominent: mixed-pixel effects linked to complex field geometries and sizes.
Field shape and size represent the most significant source of error in DORA measurements. Irregular, elongated or fragmented parcels increase the likelihood that a single 10 m pixel contains both field and non-field signals, thereby diluting NDVI magnitudes. As explicitly calculated in Table 2, the error magnitude is inversely proportional to field size, with small fields (< 0.5 ha) experiencing substantially higher uncertainty. The data show that fields below 0.5 ha can have NDVI error ranges of 4-20%, while larger fields (> 10 ha) experience much lower error ranges of just 1.2-4.8%. This demonstrates the critical relationship between field geometry and measurement accuracy, particularly for the small parcels that are common in many agricultural regions.
While existing approaches partially mitigate uncertainty, very small parcels (< 0.5 ha) remain problematic. We need more data, particularly higher spatial-resolution imagery, to address these limitations effectively. In addition, ground-based measurement campaigns are needed to establish stronger relationships between NDVI measurements and actual photosynthetic activity, allowing for better calibration of remotely sensed data as well as targeted in-field validation efforts to quantify the relationship between NDVI and biomass production across different crop types and growth stages
These steps will enhance DORA's robustness while preserving its core principles of accessibility and rapid regional benchmarking by addressing the fundamental error source: field geometry and size.

195 Park, T., Ganguly, S., Tømmervik, H., Euskirchen, E. S., Høgda, K. A., Karlsen, S. R., ... & Myneni, R. B. (2016). Changes in growing season duration and productivity of northern vegetation inferred from long-term remote sensing data. Environmental Research Letters, 11(8), 084001. (LINK)
196 Gascon et al. (2017). Copernicus Sentinel-2A calibration and products validation status. Remote Sensing, 9(6), 584. (LINK)
197 Baetens et al. (2019). Validation of Copernicus Sentinel-2 cloud masks. Remote Sensing, 11(4), 433. (LINK)

2 Deeper reflection of related works

IDDRI: An agro-ecological Europe by 2050
In 'An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercise'IDDRI[198] set out to model how an agro-ecological Europe - i.e., an agriculture with largely reduced external inputs and more ecosystem services - would impact land use, trade and food security. Through impeccable scientific rigour and clear objectives, this landmark study in our opinion represents the most important scientific contribution within the context and aims of this paper.

We find it worth citing the authors widely, who are keenly aware of their study's scope, to give the reader a great example of the model approaches we propose to advance from (see Box 1).

The authors set out to model a TYFA scenario, which they present as a desirable path for the development of EU agriculture and land use. We generally agree with the development path proposed.

The TYFA (Ten Years For Agroecology) scenario outlines a transformative vision for European agriculture by 2050, centered on the widespread adoption of agroecological principles, the cessation of imported plant proteins, and a transition toward healthier, more sustainable diets. Although it projects a 35% reduction in caloric output compared to 2010 levels, the scenario is designed to ensure that all Europeans continue to have access to sufficient, nutritious food while also maintaining a degree of export capacity. Crucially, TYFA aims to significantly reduce the European Union's global food footprint by promoting regional self-sufficiency and minimizing reliance on resource-intensive imports.
The scenario is also projected to lead to a 40% reduction in greenhouse gas emissions from the agricultural sector, largely through more circular and localized nutrient cycles, improved soil management, and a shift in land use practices. In addition, TYFA promotes biodiversity recovery and the conservation of natural resources by emphasizing diverse crop rotations, temporary grasslands, agroforestry, and other practices aligned with organic and regenerative farming systems.
Yield reductions in TYFA are conservatively estimated, with declines of around 25% for cereals, 20–45% for oilseeds and protein crops, and 5–20% for fruits and vegetables. However, these figures do not account for the potential yield improvements resulting from agroecological innovation and increased investment in research and development, —an area currently underfunded relative to conventional agriculture. Studies such as those by Ponisio et al. indicate that the yield gap between organic and conventional systems can be substantially reduced, particularly through the adoption of complex rotations and mixed cropping, —both central elements of the TYFA approach. Other research, including that by Bretagnolle et al., highlights how key ecosystem services like pollination, which are supported in organic systems, can further enhance crop yields, especially for oilseeds and protein crops.
Critiques of agroecological yield assumptions often point to hidden nitrogen dependencies in organic systems, particularly through manure inputs linked to imported feed crops from regions like Latin America. However, these concerns are not applicable to the TYFA model, which explicitly rules out the importation of plant proteins and emphasizes the need to close nutrient cycles within Europe. Achieving this requires thoughtful redesign of cropping systems to manage nitrogen effectively through diversified rotations, including legumes and grasslands. TYFA also addresses pest and disease management through ecological means by restoring the complexity and diversity of cropping systems that, further reinforcing its alignment with organic principles.

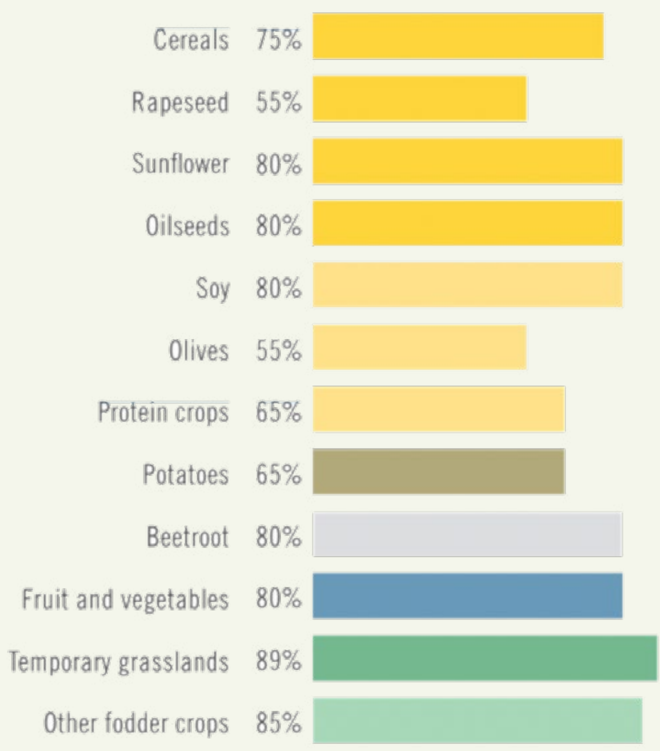


Figure 26. Yield gaps between TYFA 2050 and 2010 yields.

The authors state "It is clear that TYFA presents a utopia. [...] the conditions for the feasibility of this scenario needs to be explored."

This study on Regenerating Full Productivity aims to

198 Schiavo et al. (2021). An agro-ecological Europe by 2050: What impact on land use, trade and global food security?
IDDRI. (LINK)

integrate what the IDDRI authors wisely anticipated, but not yet modeled or accounted for: the effects of synergy and innovation due to regenerating land use management that improves agroecosystem health and productivity.

We seek to demonstrate that it is possible to positively influence yield by mitigating negative environmental ‚externalities' while boosting positive ‚externalities' on soil health through regenerating land use management. Especially, when put into the context of climate volatility, pest and disease pressure. The Utopia already exists on many farms and the feasibility of dissemination of the innovations to all farmers are largely possible, though dormant.

The inherent epistemological, methodological and data-related drawbacks of the TYFA scenario study are found within our study's results. It associates significant productivity drops to the reduction of off-farm inputs (extensification) while not being practically instructive on how to enhance the necessary synergistic effects of bio-intensification. The findings of our study show that synergistic effects are already an empirical reality, as well as our knowledge on how to best incentivize those.

Agora Agriculture: Agriculture, forestry and food in a climate neutral EU

The Agora Agriculture study[199] is a textbook example of the epistemological, methodological and data issues described above. It is a typical demonstration of 'the intensification mantra', a strong selection bias, and absence of practical use value.

One of the measures proposed as beneficial and modelled accordingly is introducing fast-growing monoculture trees on grasslands. Tellingly, this is the closest the Agora Agrar study comes to leaving the epistemological and methodological limitations of eco-efficiency. It equally subscribes to the Jevons Paradox by arguing that the trees make the land use management not only more eco-efficient but eco-effective by sequestering carbon.

The study assumes that integrating and intensifying a monoculture of Paulownia trees is beneficial, despite no mention of:

- Grassland soils stocking around double the soil organic carbon (SOC) of forest soils (in Germany[200])
- Diversity implications of introducing a monoculture in grasslands, agroecosystems that are still - relatively - home to the most biodiversity[201]
- The vast number of other measures available for grasslands, whose beneficial results are significantly backed by peer-reviewed literature[202]

That was only a discussion of one modeled measure of many and serves to exemplify the problems of the selection bias. Generally the study seems to have a heavy selection bias against the scientific publications that are genuinely concerned with innovative and integrative agronomic praxes[203], namely Conservation Agriculture, Syntropic Agroforestry or Holistic Grassland Management, among others. More surprisingly, scientifically established practices like cover cropping, direct seeding, intercropping, plant diversity or grazing management were not even mentioned.

Instead, the study proposes decreasing livestock and increasing legumes in crop rotations with no proposal of targeted incentives for mixed farms. Unfortunately, this assumption disregards the stark difference in opportunity costs associated with integrating legumes in crop rotations of different farm types and the detrimental ecological impacts of pressuring mixed farms.

Again sidelining livestock and mixed farms, the authors later cite their own unpublished study of a private contractor to support the claim that beef is 'the worst food', due to its supposedly low rates of CO_2 efficiency.

Ultimately, the study neither serves to bring innovative, realistic nor pragmatic knowledge to policy makers, much less to land stewards on how to adapt their management. Instead, it perpetuates an ill-guided neoclassical agroeconomic approach, highlighted through the failure to incorporate the diverse innovations in the land use sector.

Wageningen Research: Impact Assessment of 2030 Green Deal Targets

Another study we identified that is reinforcing misleading and poorly-adapted models is the Green Deal impact assessment produced by Wageningen Research, co-funded by CropLife International[204].

The study presents farmers with a questionnaire grounded in an eco-efficiency based and high-input, high single crop yield system. It asks them to estimate the impact on their yields - all other factors being equal - of reducing overall pesticide use and risk by 50%, nutrient

199 Agora Agriculture (2024): Agriculture, forestry and food in a climate neutral EU. The land use sectors as part of a sustainable food system and bioeconomy (LINK)
200 Thünen Institute. (2019). Bodenzustandserhebung Landwirtschaft: Ergebnisse der Boden-untersuchungen 2013 bis 2018. Thünen Report 71. Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries. (LINK)
201 Schöpke et al., (2024). Plant species richness increases across crop field–dry grassland edges in two German agricultural landscapes. Landscape Ecology. (LINK)
202 Carbon Cowboys. Publications. (LINK)
203 To name one of many: Freitag, M., Friedrich, T., & Kassam, A. (2024). The carbon footprint of Conservation Agriculture. International Journal of Agricultural Sustainability, 2331949. (LINK)
204 Bremmer et al., (2021). Impact Assessment of EC 2030 Green Deal Targets for sustainable crop production (No. 2021-150). Wageningen Economic Research. (LINK)

losses by 50% and fertiliser use by 20%.

The following citation is taken from the authors' presentation of the model's results under 'Scenario 4', later invalidated by the findings of this study.

"Scenario 4 analyses a cumulative impact of several farm to fork targets. Think of reduction in pesticide use and prevention of nutrient loss. This scenario shows an average production decline of between 10 and 20 percent. Some crops suffer more than others. Production volume can decline up to 30%"

No attempt was made to assess flanking or preceding eco-effectiveness and yield resilience measures (reduction in mechanical soil disturbance, physical and chemical soil balancing, biological inoculation, etc.). Moreover, their supposed sensitivity analysis fails to consider standard yield development trajectories within the conditions of climate change and exponentially increasing pest and disease pressure[205].

Generally, leading regenerative agriculture agronomists state that one must 'earn the right' to reduce harmful inputs (to integrate bio-intensification and synergy-enhancing practices before reducing harmful inputs). This is done to ensure that there are no significant yield losses, resulting in a positive impact on yields and, more importantly, farm income. The results presented in this study show how farmers not only earn that right, but make it an imperative for innovation, strategic autonomy and competitiveness for all farmers and Europeans.

World Resources Institute: A Pathway to Carbon Neutral Agriculture in Denmark

This study[206] models a pathway to carbon neutrality in Danish agriculture while simultaneously proposing a doubling of pig production by 2045; a contradiction rooted in flawed economic and biophysical assumptions.

The proposal is anchored in the disproven theory of comparative advantage in agricultural trade[207] and flawed LCA analyses of global pig production (naming Denmark as the most efficient in terms of CO2e-emissions per kg of pig meat). Their position is that further developing the Danish agricultural sector with this 'false' comparative advantage would provide global benefit, reducing leaking effects (causing more emissions in one place by saving emissions in another) making global protein supplies more carbon efficient.

To justify this, it relies on the improbable claim that South American yields will double in the coming years thanks to new GMOs, an example of technological Prometheanism unsupported by empirical data. These assumed yield increases are then used to support a speculative scenario of reforestation and carbon offsetting to balance Denmark's growing emissions.

The reality is that current standard GMO yields are deteriorating in former rainforest and savannah ecosystems throughout South America and do not provide higher yields than other varieties. Despite the billions of dollars being poured into technology and research over recent years, not one new GMO crop has yet achieved significant market penetration, let alone the exponential productivity needed to substantiate the study's claims. Cruicially, the study fails to mention the range of intended and unintended consequences of these technologies on ecosystems and the other consequences of industrialised agriculture[208].

Despite these glaring shortcomings, the authors go on to declare:

"Although this study only focuses on Denmark, its recommendations should be broadly applicable to the EU".

Such statements reflect a disconcerting lack of scientific integrity. The study serves entrenched special interests rather than genuine pathways to agricultural transformation. Its conclusions echo the flawed logics driving some of Europe's misguided agri-policy debates.

205 Curtis et al., (2018)
206 World Resources Institute. A Pathway to Carbon Neutral Agriculture in Denmark (LINK)
207 Binswanger, M. (2020). Mehr Wohlstand durch weniger Agrarfreihandel: Landwirtschaft und Globalisierung. Picus Verlag. (LINK)
208 Satsakis et al., (2017). Impact on environment, ecosystem, diversity and health from culturing and using GMOs as feed and food. Food and Chemical Toxicology, 107, 108–121. (LINK)

Further remarks

These examples reveal a troubling pattern in climate and agricultural modelling; a persistent neglect of key ecological variables, and an unwillingness to challenge dominant, path-dependent assumptions. Problematic examples include climate change crop prediction and planning models[209], which have serious problems related to insufficient data and the absence of ecological variables such as water vapour, the most abundant and important GHG in our atmosphere[210].

Similarly, global LCA methodologies such as the FAO's 'Global Livestock Environmental Assessment Methodology' discussed in figure 5 neglect long-term consequences, utilise deceptive framing and terminology, and favour unreflective intensification for whole-system detrimental eco-efficiency[211].

More concerning are those studies setting out to discredit the empirical results and innovations from the field; initiatives often developed at great personal cost by pioneering farmers and land stewards[212]. In doing so, they protect outdated scientific orthodoxy and vested interests that benefit from its maintenance[213]. These are not objective assessments, but ideological defences of a failing system.

3 Nationally compounded pioneer data, Eurostat benchmarking data, retrofitting details and survey

This Appendix 3 accessible for download under https://doi.org/10.5281/zenodo.15608841 outlines the data sources, processing methods and analytical workflow underlying this study.

Data was collected between June 2024 and March 2025 from pioneering farmers across Europe, complemented by benchmarking data from Eurostat. All pioneer data has been fully anonymized to protect farmer identity and ensure data privacy. We provide the structured datasets as used in the analysis, along with the original farmer survey instrument and a codebook explaining all variable names, units and classifications.

The accompanying workbook, built in Microsoft Excel, is an automated calculation system that compiles raw data from each country, integrating inputs from both the anonymized farmer survey and Eurostat. The workflow includes unit standardization (e.g., converting thousands of hectares to hectares), data aggregation and conversion of outputs into energy and protein equivalents. Aggregated variables are averaged over multiple years, and relative performance per hectare is calculated using the formula: (Eurostat - Pioneer) / Eurostat) × -1.

Satellite observation data is also incorporated using the same method of relative comparison. These relative differences, across both inputs and outputs, are compiled into a summary sheet, which powers the generation of the Regenerating Full Productivity (RFP) index. The integration of anonymized survey data, Eurostat benchmarks, satellite observations and Excel-based formulas creates a unified, replicable system for performance evaluation across diverse contexts.

209 Faye et al., (2023). Climate change impacts on European arable crop yields: Sensitivity to assumptions about rotations and residue management. European Journal of Agronomy, 142, 126670.(LINK)
210 Mumba, M., Ovink, H., & Rockström, J. (2025). Water is the silent currency that keeps the global economy flowing. Nature Water, 1-2. (LINK)
211 Repercussions of scientifically biased and outdated LCAs of livestock systems impact water, biodiversity, climate and public health.
212 Discussed above, and within our Policy Paper
213 Groups that have a vested interest in the perpetuation of intensive chemical and soil disturbing machinery use in agriculture and the extractive mindset associated to it. These authors display a particularly strong selection bias against modern achievements, especially in fields like soil biology or water sciences. (LINK) (LINK)

The **European Alliance for Regenerative Agriculture (EARA)** is the independent, farmer-led coordination, advocacy and collective action organisation of the movement of regenerative agriculture at the European level. EARA is striving to enable the transformation of our agrifood ecosystems through accountable ecologic, economic and social regeneration.

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