DISCUSSION PAPER

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Resolving the energy-food-nature trilemma in land use: The role of digitalisation and EU policies

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Credit: CANVA

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This Discussion Paper builds on the findings of the EPC project: "Resolving the energy-food-nature trilemma in land use: The role of digitalisation and EU policies", which was carried out in 2024-2025 with the support of Vodafone Institute for Society and Communications. This project explored how land resources can be optimised to maximise the benefits for renewable energy generation, food production, and nature restoration in line with Green Deal objectives. In particular, the project focused on how digital solutions can align the clean energy transition with food security and nature restoration objectives with regard to land use, and how European policies can help unlock this potential.

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Executive summary

Europe is grappling with an intensifying challenge in balancing land use for food production, renewable energy generation, and nature conservation. With 80% of Europe's land already used for human activities, this energy-food-nature trilemma is compounded by external pressures, including the energy crisis, rising food prices, and geopolitical tensions. These challenges risk undermining the EU's Green Deal objectives of climate neutrality and biodiversity restoration.

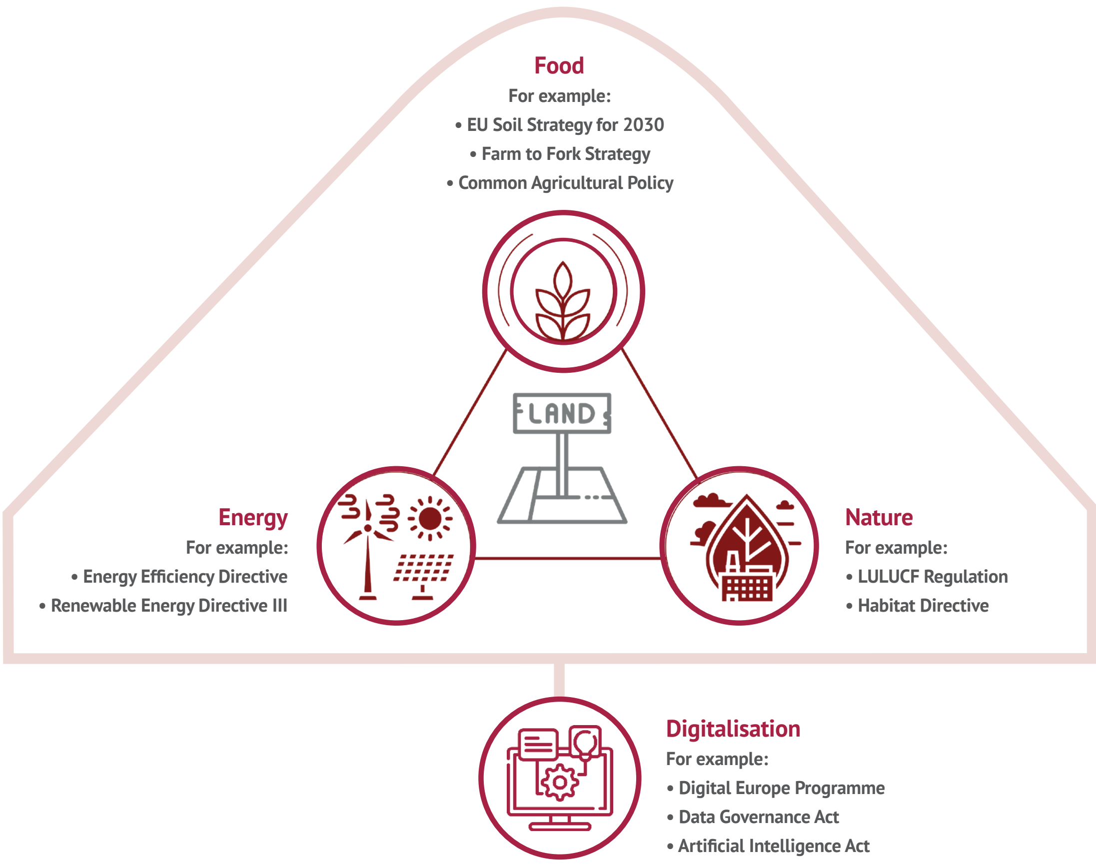
Digitalisation offers transformative solutions to address these pressures (see Figure 1). Tools such as earth observation systems, artificial intelligence (AI), and innovative farming technologies can enhance land-use efficiency, reduce trade-offs, and foster synergies. However, uneven access to digital infrastructure, fragmented data governance, and unmanaged environmental risks from digital technologies limit their effectiveness.

To ensure digital solutions support sustainable land management and align with EU policy objectives, this paper stresses the need to:

- **Develop a digitally-driven vision for land use** to balance food, energy, and biodiversity needs while enhancing sustainability and resilience. The vision should aim to hamonise the policy framework and inform the upcoming Vision for Agriculture and Food, Clean Industrial Deal, and post-2027 CAP framework.
- **Enhance digital capacity, data governance, and interoperability** to enable policymakers, farmers, and conservation actors to feed and retrieve data and make informed decisions based on real-time, harmonised datasets.
- **Promote digital solutions that enable mixed-use practices for land sharing and innovative farming practices for land sparing** to balance energy, food, and biodiversity demands while reducing pressure on land.
- **Address the environmental and social costs of digitalisation** by implementing measures to minimise resource consumption, prevent and manage e-waste, and promote equitable access to digital infrastructure across rural and underserved regions.

Figure 1

ENERGY-FOOD-NATURE TRILEMMA IN LAND USE



Introduction

Europe is facing a significant challenge in managing its land resources, with growing competition between food production, renewable energy generation, and nature restoration. This becomes more evident with the growing geopolitical rivalries and the Russian invasion in particular, driving the surge in energy and food prices, respectively. Around 80% of Europe's land is already used for human activities, predominantly in agriculture, forestry, and infrastructure.[1] This creates significant pressure on biodiversity and contributes to environmental degradation, presenting a critical dilemma for EU policymakers. The energy-food-nature trilemma highlights the urgent need to balance these competing demands, particularly in light of the European Green Deal's climate neutrality and nature restoration objectives.[2]

Europe is facing a significant challenge in managing its land resources, with growing competition between food production, renewable energy generation, and nature restoration.

Recent political reports and strategic documents on the future of the EU underline the need for promoting innovative solutions and policy coherence to address competing demands — whether for energy, food production, or nature restoration — while safeguarding Europe' competitiveness, sustainability, and resilience.[3] Achieving this balance requires a nuanced approach that accounts for the complex interplay of land-use priorities, setting the stage for innovative strategies, including the role for data and digital solutions, to help resolve Europe's energy-food-nature trilemma.

THE ROLE FOR DIGITALISATION

In this context, digitalisation offers transformative tools for optimising land use. For example, technologies such as earth observation and artificial intelligence (AI), can support decision making and promote synergies between demands for land use. Advanced spatial analysis models allow citizens to visualise and analyse spatial data related to land use, strengthening public engagement.[4] Digital tools for precision farming, data management, and information sharing can reduce land demand while simplifying working conditions and ensuring compliance with environmental rules.[5] Despite these prospects, cross-sectoral data and access to digital infrastructure are not yet fully available, while the EU only partially harnesses the power of digital tools to manage the trade-offs inherent to land use.

Digitalisation offers transformative tools for optimising land use.

SCOPE AND METHODOLOGY

This Discussion Paper explores the state of play, challenges, and prospects with using digital solutions to optimise and prioritise land use in view of competing demands for energy generation, food production, and nature restoration. It looks at ways to enable synergies between these uses while minimising trade-offs. The paper discusses how EU policies and investments can support better land management and the uptake of data and digital solutions for reaching this goal. In this Discussion Paper, the terms 'food production', 'energy generation', and 'nature restoration' refer to all respective activities that entail the use of land, this includes those uses that indirectly cause land use to change elsewhere.[6] Moreover, the terms 'food production' 'agriculture' and 'farming' are used interchangeably; the same applies to 'nature' and 'environment'.

The Discussion Paper is based on the EPC's independent research conducted in 2024-2025 as part of the project "Resolving the energy-food-nature trilemma in land use: The role of digitalisation and EU policies". The research draws its findings from the following sources:

- A literature review of the relevant legislation, studies, and online information;
- Findings from an EPC workshop and follow-up correspondence with relevant stakeholders. The workshop took place on 31 October 2024 and investigated the role of digitalisation in optimising land use.[7]

The paper provides an overview of how digital solutions might contribute to sustainable land use planning and management in the EU. It includes relevant case studies and a discussion on current challenges. Building on the latter, it explores enablers and barriers in EU policies and financial tools to help policymakers make informed decisions and to provide them with recommendations that could be easily put into action. The overall aim of the paper is to provide insights and support future policy development and implementation in the land use sector as part of the EU's new institutional cycle.

2. The role of digitalisation in sustainable land use

2.1 OVERVIEW OF TOOLS FOR LAND USE OPTIMISATION

Digitalisation is playing an increasingly vital role in the sustainable management of land, especially when it comes to balancing competing demands from agriculture,[8] renewable energy,[9] and nature restoration.[10] Earth observation tools like the Copernicus Land Monitoring Service (CLMS) provide high-resolution satellite data that helps policymakers and stakeholders monitor land-use changes, environmental conditions, and resource availability. For instance, CLMS can identify degraded or underutilised land by analysing soil quality, vegetation health, and land cover trends. This data can support decisions about where renewable energy projects or restoration efforts may be implemented with minimal impact on productive farmland or biodiversity.

Digitalisation is playing an increasingly vital role in the sustainable management of land, especially when it comes to balancing competing demands from agriculture, and nature restoration.

By leveraging spatial analysis models and AI tools such as the European Land Cover map at 10-meter resolution (ELC10) and digital elevation models for renewable energy planning, policymakers are better equipped to optimise land use.[11] For instance, these tools enable the identification of areas that can support both renewable energy projects and food production, such as in agri-photovoltaic systems, where solar panels are installed above crops or to provide shade for livestock, allowing both energy generation and agricultural activities to take place on the same land. Spatial analysis models and AI tools also make it possible to identify degraded land with optimal prospects for renewable projects, thereby minimising impacts on high-value agricultural or natural areas. Indeed, AI-driven models can predict the potential impacts of land-use decisions and help prevent or address conflicts between different uses.[12] This predictive capability is crucial as Europe looks to meet its sustainability goals while ensuring that agricultural production and biodiversity conservation are not compromised by the push for renewables.

Digitalisation also has the potential to revolutionise the agrifood system, as digital tools can bring about a significant reduction in the demand for land and reduce the pressure of farming on ecosystems. For instance, satellite imagery, sensors, AI, Internet of things (IoT), drones, and robots can enhance precision in agricultural practices and facilitate resource-efficient production methods,[13] but also provide early-warning systems and boost bio-tech innovation for more sustainable food production.[14] Despite the resilience of the agri-food system facing growing threats, Europe's livestock sector continues to make inefficient use of scarce productive land for feed production.[15] Now, digital innovations for precision livestock farming, such as biometric sensors, big data, and blockchain technology, are making production of animal products less resource intensive.[16] However, these developments are not without challenges and ethical implications for animal welfare.[17] On the other side of the spectrum, AI and data digitisation are fuelling new ways of designing and scaling up the production of animal-free proteins.[18] These developments could help reduce farmland needed to produce our food freeing land for nature restoration and energy transition targets — and provide a much-needed push towards net zero.[19]

2.2. CASE STUDIES

Energy & farming

BayWa r.e has designed a hybrid wind and solar power plant to be compatible with farming systems, as well as a semi-transparent solar module that allows sunlight to pass through the photovoltaic system allowing crop growth without impacting solar panel performance. These developments were fuelled by **AI-driven simulation**, large-scale engineering software, and **Geographic Information Systems** (GIS) technology. Agri-photovoltaic systems (Agri-PV) not only reduce heat stress for livestock, improving animal welfare, but also foster biodiversity by creating microhabitats.

Fraunhofer Institute has been testing different solar panel combinations with fruit, grains, and fish farming. Using this type of vertical agrivoltaics, or the dual use of land for solar energy production and agriculture, maximises land use in arable farmland. In Germany, Agri-PV are set to provide a protective function in fruit orchards against adverse climate. In Vietnam, they are experimenting with combining solar power generation and aquaculture in pond farming. Fraunhofer Institute uses **digital twin technologies** to simulate and predict the performance of Agri-PV systems, enabling real-time optimisation of solar tracker positions to balance photovoltaic output with food production needs. In this context, the institute found that **AI-driven tools** enhance decision-making processes, improving the efficiency and productivity of combined solar and farming operations.

SunAgri is currently developing Agri-PV projects combining solar panels with viticulture and arboriculture in the regions of southern France most affected by climate change. They have developed a software that enables the creation of **control algorithms** that allow the photovoltaic panels to be adjusted in real time in order to optimise plant growth.

Farming & nature

The LANDSUPPORT project integrates **satellite data** from the Copernicus Land Monitoring Service and **spatial analysis models** on vegetation in their GeoSpatial Decision Support System (S-DSS) to help policymakers identify how land can be used to meet both agricultural and environmental demands. The S-DSS incorporates thematic maps on topics such as nitrate vulnerability, potential solar radiation, and soil data, providing a more nuanced understanding of land-use dynamics.

The LIFE RESILIENT FORESTS project utilises **data integration modules** and **optimisation algorithms** to assess forest health and predict the effects of climate change on forest ecosystems in southern Europe. Their Decision Support System (DSS) toolkit enables policymakers and forest managers to take proactive measures to preserve biodiversity and maintain the forests' vital role as a carbon sink, namely removing a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.

The MIXED and AGROMIX projects support the development of European Mixed Farming and Agroforestry Systems (MiFAS) that optimise efficiency and resource use, reducing land demand for traditionally conflicting land uses. These projects explore the potential of using **virtual tools to transform stakeholder engagemen**t and of developing agroforestry field guides to facilitate informed decision-making for integrating trees into farming systems.

Optimised farming & interoperability

SynApps is a **decision-support tool** that helps farmers adopt nature-based solutions for crops by offering tailored alternatives to chemical products. Similarly, Libelium provides **sensor technology** and an **IoT-based platform** to improve yields by enabling observation, measurement, and response to environmental conditions, diseases, and pests. This kind of tool can reduce the indirect impact of farming on other land uses, thereby reducing conflicts.

Solar foods and Farmless are pioneering sustainable protein production methods that significantly reduce reliance on traditional agriculture. Both companies use **digital bioinformatics and bioprocessing** techniques to cultivate microorganisms into edible protein using air, electricity, and fermentation. By decoupling protein production from traditional agriculture, these technologies can substantially reduce the demand for arable land.

The DEMETER project promotes **interoperable** smart farming **IoT platforms** using a farmer-driven, multi-actor approach across the entire supply chain. This kind of development has the potential to improve quality data availability, reduce fragmentation, and help resolve conflicts between land uses by offering data-driven solutions for optimising land management.

2.3. CURRENT CHALLENGES IN THE DIGITAL WORLD

Data fragmentation and inconsistent data quality

Despite the benefits of digitalisation in land-use management, there are significant challenges to its effective integration. One is the fragmentation of data across sectors. Energy companies, farmers and nature protection agencies often collect data in silos and lack coordination mechanisms, which result in inconsistent information sharing — both within and across sectors. This fragmentation makes it difficult to develop cohesive strategies that balance the needs of multiple sectors. For example, biodiversity monitoring in Europe is fragmented and inconsistent across countries, which hampers the development of integrated policies that address the interconnectedness of agricultural practices, renewable energy development, and nature conservation.[20] Similarly, in an increasingly data-driven farming sector, data lock-in and fragmentation give way to unconnected data silos controlled exclusively by certain economic actors, such as agricultural giants and technology providers.[21] While large farming and agrochemical corporations, machine producers, and technology providers collaborate to enhance their data capabilities, this can raise barriers to data access for smaller competitors or new market entrants.[22]

The limited availability of high-quality data, particularly at the local level, presents another challenge to devising cross-sectoral digital strategies in the EU. While digital tools like the CLMS provide excellent large-scale data, there are often gaps in the collection of granular data at ground level for validation and calibration, especially in rural or underdeveloped regions. These data gaps limit the precision of digital tools for land-use management, making their effective application difficult in areas where land-use conflicts are the most prominent.[23] With Europe's landscapes increasingly fractured, these limitations complicate efforts to develop comprehensive strategies that balance agricultural needs, energy infrastructure, and nature restoration.[24] Overcoming these challenges will be key to ensuring that digital solutions can deliver on their potential to optimise land use in the EU.

Data gaps limit the precision of digital tools for land-use management, making their effective application difficult in areas where land-use conflicts are the most prominent.

Digital divide and usability

In Europe, more than half of the rural population lacks basic digital skills.[25] Unequal access to digital literacy and technologies deepens socio-economic disparities, leaving rural or underserved communities behind.[26] Even as a whole, the EU has a critical shortage of digital skills, especially given the growing need for specialised, cross-sectoral expertise. A recent survey by the European Investment Bank indicates that Europe lags behind global peers, highlighting a pressing need to close the digitalisation gap.[27] A substantial 'digital divide' exists between sectors and member states.[28] While some industries and countries have advanced rapidly, many sectors, including agriculture, have not. These digital skills and digital uptake gaps pose a significant barrier to implementing land-use policies that rely on complex technologies, which require digital literacy, digital infrastructure and skilled operators to manage and interpret large volumes of data. If unaddressed, this divide will likely cause further delays and inefficiencies.

Additionally, digital platforms must be designed with end-users in mind to maximise adoption. Farmers and local governments often require simple, user-friendly interfaces that provide actionable insights rather than raw data. For instance, platforms like the Land Support Project demonstrate how user-centric GIS tools can transform complex datasets into accessible solutions, bridging the gap between scientific outputs and practical decision-making.

Externalities of digitalisation

The digital divide is not only in terms of skills and infrastructure. As the EU works to integrate digital solutions, the issue of affordable energy also hampers the uptake of land-use technologies across member states. In other words, the EU needs strategies to reduce energy costs, ensuring that all regions and industries can leverage digitalisation effectively without widening the gap in competitiveness.

Equally important to bridge this divide are raising awareness on the benefits of cross-sectoral data sharing in view of competing demands for land and addressing concerns over privacy breaches. Pervasive data collection by digital tools risks breaches and misuse, which may compromise individual and organisational privacy.[29]

In addition, big agri-businesses and technology companies may use the data obtained to disseminate unsustainable solutions exacerbating land-use conflicts.[30] Moreover, AI-based tools can perpetuate biases and foster unsustainable decisions, leading to similar outcomes.

If digitalisation is to help resolve the energy-food-nature trilemma sustainably, the environmental impact of digital technologies cannot be overlooked. The operation of data centres, AI tools, and satellite systems requires significant energy consumption, potentially offsetting some of the sustainability gains achieved through digital solutions. The IEA stated that data centres already accounted for 1% to 1.5% of global electricity consumption in 2022 and are responsible for 1% of energy-related GHG emissions, and that was before the AI boom began with ChatGPT's launch at the end of that same year.[31] To understand the scale of this impact, the aviation sector is responsible for 2% of global GHG emissions.[32]

If digitalisation is to help resolve the energy-food-nature trilemma sustainably, the environmental impact of digital technologies cannot be overlooked.

The production and disposal of digital devices, such as satellites and servers, significantly contribute to electronic waste, which poses additional long-term environmental risks.[33] In 2022, Europe generated approximately 17.6 kg of e-waste per capita, with less than 40% being recycled, leading to environmental pollution and health hazards.[34]

Similarly, the production of digital technologies relies heavily on critical minerals and rare earth elements: the rapid growth of digital technologies poses challenges for the supply of these critical materials. Furthermore, the extraction of rare earth minerals and metals for electronic components can result in habitat destruction and pollution.[35]

Financing gaps

Fragmented and insufficient budget allocations hinder the adoption of digital tools for sustainable land-use management. Funding mechanisms such as the Digital Europe Programme (€7.5 billion) and the Common Agricultural Policy (€387 billion) provide substantial support for digitalisation, but their resources are broadly allocated and fail to systematically target integrated solutions for agriculture, energy, and biodiversity.[36]

Investment in digital infrastructure remains inadequate, particularly in rural areas. More than 60% of rural households lack access to Very High-Capacity Networks (VHCN),[37] as reported in the 2022 Digital Economy and Society Index (DESI).[38] This connectivity gap highlights the need for more focused budget allocations to modernise infrastructure in underserved regions.[39]

Without better-targeted and equitable financial strategies, the potential of digital tools to optimise land use will remain unrealised.

Uneven funding distribution across member states further exacerbates regional disparities, leaving weaker economies unable to implement large-scale digital projects.[40] Without better-targeted and equitable financial strategies, the potential of digital tools to optimise land-use management will remain unrealised.[41]

As previously mentioned, digital solutions are being used to optimise land use, but their effectiveness is hindered by several challenges and limitations. This calls for a robust EU policy framework to drive the development and adoption of digital solutions, paving the way for sustainable and efficient land use planning and management, a topic explored in the next section.

3. EU policy framework

Building on the potential of digitalisation to enhance sustainable land use, the EU has introduced policy initiatives aimed at balancing energy production, food security, and nature restoration. These policies are crucial components of the European Green Deal, which aims to make Europe climate neutral by 2050. However, EU policies are not yet fully harnessing the power of digital tools to manage the trade-offs inherent to land use — nor are they fully addressing the externalities associated with the digital transition.

3.1. CURRENT FUNDING FRAMEWORKS

We are witnessing increased financing for research and innovation in the EU: the European Innovation Council (EIC) has pledged to support European deep-tech research and high-potential start-ups with €1.4 billion for 2025, which means an increase of nearly €200 million in comparison with 2024.[42]

Not only is there more funding available, but the 2025 EIC's work programme has been improved in several ways that will also benefit research and innovation.[43] Notably, better access to equity funding was introduced with the EIC Strategic Technologies for Europe Platform (STEP) scale-up scheme following the adoption of the STEP regulation earlier this year. This scheme will support companies working in strategic technology areas with substantial investments and co-investment opportunities, providing the financial backing necessary to drive innovation in digital and resource-efficient sectors critical to Europe's future. This could open up opportunities in the scope of investments in the energy, nature and agri-food sectors.

With an overall budget of over €8.1 billion, the Digital Europe Programme aims to drive Europe's digital transformation, aligning the EU's strategic objectives outlined in the 2030 Digital Compass: The European Way for the Digital Decade" and the "Path to the Digital Decade" policy framework.[44] The Digital Europe Programme functions within a broader ecosystem, complementing other EU initiatives such as Horizon Europe, which focuses on research and innovation; the Connecting Europe Facility, which targets digital infrastructure; the Recovery and Resilience Facility, which provide transitional support to EU member states' reforms and investments, and structural funds. This integrated approach is a cornerstone of the EU's Multiannual Financial Framework for 2021-2027, ensuring a strategy toward digitalisation across multiple sectors. Yet these tools are not sufficiently aligned in their goals. For instance, while the Digital Europe Programme focuses on digital solutions, the allocation of funds for land-use management systems that combine digital and green agendas often remains fragmented and unclear.

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Digitalisation is also framed as an enabler for modernising agriculture, improving productivity, and meeting sustainability targets under the Common Agricultural Policy (CAP). A CAP funding mechanism under the European Agricultural Fund for Rural Development specifically targets structural changes needed for the digital and green transitions with resources proceeding from the Next Generation EU Fund.[45] Horizon Europe funds set aside to support specific research and innovation in food, agriculture, rural development, and the bioeconomy are intended to facilitate research and digital solutions for the dissemination of agricultural knowledge and innovation systems (AKIS).[46] Yet, there remains a significant gap in the implementation of these funds for comprehensive data-driven tools designed for sustainable land use. Moreover, more attention must be paid to funding specific projects that can support data interoperability and enable better integration between different sectors.

3.2. EU'S NATURE, AGRICULTURE AND ENERGY POLICIES

Balancing multiple demands for land use and digitalisation

The EU's policies affecting land use include the Biodiversity Strategy 2023 with its Nature Restoration Law, the Renewable Energy Directive (RED), the Common Agricultural Policy (CAP), and the Land use, Land-Use Change, and Forestry (LULUCF) Regulation (see Annex 1). In addition, the Habitat and Birds Directive (Natura 2000), the EU Soil Strategy for 2030, the Forest Strategy, the Farm to Fork Strategy, and the Water Framework Directive also affect land use in Europe.

The cross-linkages between the nature-, agriculture- and energy-related policies become evident when considering the multiple demands placed on Europe's limited land resources.

The cross-linkages between the nature-, agriculture- and energy-related policies become evident when considering the multiple demands placed on Europe's limited land resources. For instance, while the CAP primarily focuses on supporting European farmers, alignment with both the Nature Restoration Law and the Renewable Energy Directive is essential, as agricultural lands often serve multiple purposes providing food, supporting renewable energy infrastructure, and acting as vital ecosystems. In this same direction, the LULUCF requires member states to ensure a balance between carbon emissions and removals in land use sectors, thereby making the sustainable management of forests and other land crucial for meeting the EU's climate targets.[47] The Nature Restoration Law aims to restore ecosystems across the EU, but this must be done in a way that complements the CAP's bid towards food production and the Renewable Energy Directive's ambitious targets for expanding solar and wind energy infrastructure. As renewable energy projects seek more land, often on arable or biodiversity-rich areas, balancing these demands becomes increasingly complex. As shown in Section 2.2, digital tools like the CLMS can facilitate real-time monitoring of land use, helping policymakers identify where renewable energy projects can coexist with food production and restoration efforts, where exclusive use should be allocated, and where, conversely, conflicts may arise.[48]

The current policy framework lacks harmonisation and gaps remain in how effectively these policies incorporate digital solutions.

A notable impediment to aligning different land-related policies is the lack of a coherent strategy on using data and digital solutions with regard to land use. The current policy framework lacks harmonisation and gaps remain in how effectively these policies incorporate digital solutions such as satellite monitoring, AI-driven spatial analysis, and data-sharing platforms, which are essential for optimising land use. For example, the proposed soil monitoring and resilience directive is expected to tackle some of these gaps with the goal of improving soil health, not necessarily to optimise land use.[49] Moreover, its effectiveness will depend on the development of specific guidelines and resources that promote systemic adoption of digital technologies.

Digitalisation in specific land-use policies

Furthermore the incorporation of digitalisation in specific land-related policies is sporadic. For example, the Nature Restoration Law emphasises that digital tools such as remote sensing, CLMS, and GIS can significantly improve efficiency and cost reduction.[50] Yet it lacks explicit provisions detailing the integration of these digital technologies into its framework. The law does not specify how AI and satellite monitoring should be employed to achieve restoration targets, which could lead to inconsistent application across member states. Additionally, the absence of a clear data-sharing framework poses a significant challenge for data-driven decision making.

The incorporation of digitalisation in specific land-related policies is sporadic.

In the case of the LULUCF, digitalisation could be particularly instrumental in accurately measuring carbon sequestration capacities of various land types through remote sensing and AI-driven soil carbon mapping.

Yet, the Regulation does not systematically integrate such technologies into its framework.[51] The absence of a standardised framework for data collection and verification complicates efforts to harmonise reporting across member states.[52] Moreover, gaps in interoperable platforms and real-time monitoring capabilities restrict policymakers' ability to optimise land allocation for carbon capture without compromising agricultural productivity or biodiversity goals.

As for the energy sector, the Renewable Energy Directive (RED) acknowledges the role of digitalisation in advancing the renewable energy transition towards climate neutrality.[53] In this sense, the RED is supported by the EU Action Plan on digitalising the energy system launched in 2022.[54] The Action Plan provides a blueprint for the adoption of digital tools across energy policies, the RED, Energy Efficiency Directive (EED), and Energy Performance of Buildings Directive (EPBD), to accelerate the twin green and digital transition. However, the plan is incomplete as it fails to provide clear mechanisms to ensure effective implementation across EU countries, standardise data collection and share protocols.

Similarly, the CAP and its Strategic Plans for 2023-2027 recognise the role of digitalisation in modernising the agriculture sector.[55] Nevertheless, the framework fails to allocate sufficient resources to match the broad range of needs to be met to accelerate the digital transformation of the sector.[56] For instance, there is significant variation in the adoption of digital technologies across EU member states due to differences in financial, technological, and institutional capacities.[57] Moreover, the absence of interoperable platforms for real-time data sharing and of upskilling programmes inhibits collaboration across stakeholders. Unless these needs are met fully, the potential for digital tools to optimise the demand for land of the agriculture sector will remain untapped.

In conclusion, integrating coherent digital strategies across agriculture-, energy-, and nature-related policies is complex and requires further effort to work seamlessly across the EU. The next section explores enablers and barriers in the EU's digital agenda towards this goal.

3.3. THE DIGITAL AGENDA

European data agenda

A vast amount of data generated in the EU remains underutilised due to legal and infrastructural barriers.[58] The 2020 European Strategy for Data aims to address these challenges by fostering data sharing and access. Supporting this effort are the Data Governance Act (DGA), which promotes data availability, and the Data Act (DA), which defines who can derive value from data and under what conditions. Within this framework, Common European Data Spaces make it possible to access and reuse data securely, encouraging data sharing and interoperability between holders and users while enabling easier access through connected, sector-specific data spaces. While these measures empower citizens with greater access and control over their data, widespread digital illiteracy hinders data protection, a responsibility that often falls heavily on individuals. Despite a solid framework of policy initiatives on digital skills and education, the EU is falling short of its related 2030 digital targets.

Currently, data spaces are being developed in 14 strategic areas, including agriculture, energy, and manufacturing. Funding for this ambitious effort comes from the Digital Europe Programme, which promotes digital technology use across society and the economy. Central to the Common European Data Spaces initiative are shared data infrastructures and governance frameworks that enable data pooling and access. The European Data Innovation Board (EDIB), established under the Data Governance Act, is responsible for setting appropriate guidelines. Data Spaces could enable access to key data on agricultural productivity, soil quality, biodiversity indicators, wind intensity, solar radiation (e.g., global horizontal irradiance), grid connectivity, and more. Such data, when combined with satellite information, would power optimisation algorithms that balance nature restoration, food production, and renewable energy. For this reason, it is paramount to reduce data fragmentation, enhance interoperability, and improve ground data quality.

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Within the Green Deal Data Space, the GreenData4All initiative aims to address challenges such as fragmented and disconnected data systems.[59] But the Green Deal Data Space is still in its conceptual phase, with numerous projects yet to be fully implemented, leaving its effectiveness in addressing these key challenges unproven.[60] EU investment through the Digital Europe and Horizon Europe programmes supports technical standards, interoperability, and secure infrastructure, such as cloud environments, which are essential for a unified EU data market. Ensuring equal access to these data pools will be critical to enable digital solutions that help navigate complex land-use decisions and trade-offs. Many of these solutions rely heavily on advanced technologies, particularly AI, to analyse vast datasets and provide actionable insights. Recognising the transformative potential of AI, the EU has developed a comprehensive framework to govern its use and ensure it aligns with societal values and objectives.

AI Legislation

The EU's approach to Artificial Intelligence is anchored by the AI Act, which sets out a comprehensive legal framework to govern the use of AI technologies. The legislation is not tailored to the land use sector, but it is relevant to the sector nonetheless given the importance that AI systems could have in collecting data, sharing information, using modern machinery, and providing insights for informed decisions on future land use practices.[61] Therefore, this legislation, along with related frameworks such as the Data Act, the Data Governance Act, and sectoral strategies, affects the integration of AI in addressing the energy-food-nature trilemma.

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Introduced as the first legal initiative of its kind worldwide, the AI Act aims to ensure that AI systems deployed in the EU are safe, lawful, and respectful of fundamental rights. It introduces a risk-based approach, categorising AI systems into unacceptable, high-risk, limited-risk, and minimal-risk applications.[62]

Under the AI Act, certain systems used in agriculture and land management may be classified as high-risk, particularly if they serve as safety components of critical infrastructure or influence decisions.[63] These systems are subject to stringent compliance requirements, including provisions on data governance, transparency, and human oversight. The latter align with broader EU initiatives like the European Strategy for Data and the Common European Data Spaces, which emphasise the need for high-quality datasets for training AI models and ensuring interoperability across sectors.[64]

The AI Act's relevance to the agri-food sector is particularly evident in AI-driven solutions for precision agriculture, biotechnology, crop monitoring, and climate adaptation. While these innovations hold transformative potential, the legal obligations under the AI Act, such as post-market monitoring and conformity assessments, could create barriers for smaller developers in the agri-food space. Addressing these challenges requires harmonised support through programmes like Horizon Europe, which already funds research in Explainable AI and sector-specific AI applications.

Mitigating measures for digitalisation's impact on sustainability

The current EU legislation lacks clear provisions to address some of externalities of the digital transition. For instance, it relies heavily on reporting and transparency to reduce GHG emissions from data centres, lacking enforceable energy consumption or emission reduction targets for data centres.

The Ecodesign for Sustainable Products Regulation aims to prevent e-waste through design improvements and promotes the reuse, recycling, and recovery of such waste to reduce its environmental impact. However, the policy framework and concrete eco-design requirements for electronics still remain to be finalised.

3.4. THE NEW DIGITAL AND GREEN AGENDAS

President von der Leyen's Political Guidelines for 2024–2029 explicitly acknowledge the critical intersection of green and digital transitions.[65] In these guidelines, the European Data Union Strategy is proposed to enhance productivity in the EU through digital technology and open data, while the upcoming Clean Industrial Deal and digital tools are set to promote a decarbonised economy and make progress towards meeting the 2050 net-zero targets. Similarly, the upcoming Vision for Agriculture and Food is intended to ensure the sustainability of the agri-food sector within the boundaries of our planet. Reducing the demand for land by making the energy and food sectors less resource intensive goes hand-in-hand with decarbonisation. However, the document fails to present actionable, integrated policies for improving the uptake of digital tools towards this goal, and fails to shed light on how to improve policy coherence in the nature, agriculture, and energy sectors.[66] Furthermore, the lack of an explicitly defined mechanism to align data-sharing platforms, artificial intelligence (AI), and cross-sector policymaking risks perpetuating the existing policy silos.

President von der Leyen's Political Guidelines for 2024–2029 explicitly acknowledge the critical intersection of green and digital transitions.

A clear example lies in the guidelines' focus on enhancing infrastructure for AI without a direct link to applications such as satellite monitoring for ecosystem restoration or, more broadly, land-use management. While fostering productivity and competitiveness through digitalisation, the guidelines insufficiently consider how digital advancements could be deployed across agriculture, energy, and environment domains.[67] Moreover, there's little emphasis on supporting capacity building in smaller member states and rural areas, which lack the digital expertise required to engage with EU-wide platforms effectively.

Following the publication of the Political Guidelines, President von der Leyen sent a Mission Letter to each of the Commissioners-designates who were subsequently questioned by the Parliament in their Confirmation Hearings. Some of the statements in the Mission Letters, emphasise using digital tools such as satellite systems and data-sharing platforms for biodiversity monitoring and, more broadly, to advance the green transition. But there is little exploration of how to ensure harmonisation across member states when implementing such technologies. For example, the Mission Letters to Commissioners with a prominent stake in the land use sector do not address the challenges posed by fragmented governance or inconsistent data protocols in the application of digital solutions for land-use optimisation.[68] Neither do they sufficiently reference tangible solutions capable of bridging the digital divide and accelerating the transition to a more sustainable, harmonised, and synergetic land-use management practices in the EU.

4. Conclusion and recommendations

To resolve the energy-food-nature trilemma, the EU must take decisive action to better integrate digital tools into its land-use policies. Digitalisation offers promising tools to address these interconnected demands, enabling more efficient, equitable, and sustainable use of limited land resources (see Figure 1). However, achieving this potential requires addressing key barriers, including fragmented data governance, insufficient and uneven access to infrastructure, and the externalities of applying digital solutions. The following EU recommendations outline how this can be achieved:

STRATEGIC DIRECTION

- Bearing in mind ongoing climate change, rising geopolitical rivalries, and energy and food affordability challenges, **the EU should create a vision for land use management** that strengthens Europe's sustainability and resilience while balancing competing demands for food, energy, and biodiversity. **Digitalisation should be at the core of the new land use strategy** since digital tools and data sharing can help foster land use optimisation and enable synergies between multiple land uses scenarios. The strategy would inform the upcoming Vision for Agriculture and Food, the Clean Industrial Deal, and the post-2027 CAP framework.

- **The Commission must work closely with relevant stakeholders**, including member states, farmers, energy operators, nature protection agencies and civil society, to improve data governance and align incentives and standards on data sharing concerning land use.

- **EU institutions and member states must enhance digital infrastructure and skills** to bridge the digital divide afflicting the Union. They should step up the investments to fill the connectivity gap, spur innovation, and improve the uptake of digital solutions.

- **The negative side effects of digitalisation must be addressed** to prevent the proliferation of trade-offs between the digital and green transition in the EU. The EU and member states must develop rules and standards for and invest in digital solutions that are energy- and resource-efficient.

CONNECTING LAND USE AND DIGITAL POLICIES

- **Integrate digital tools into land-related EU policies:** The EU should introduce requirements for the use of digital tools, such as the CLMS and AI models, in the implementation of key policy frameworks, such as the Nature Restoration Law, Renewable Energy Directive, and Common Agricultural Policy. It should also ensure that these tools are backed by extensive ground-level data to enhance accuracy and reliability. This would enable real-time monitoring of land-use changes and improve the accuracy of land-use planning across sectors. To this end, a bottom-up policy approach should be favoured to foster the uptake of these tools by local authorities, farmers, and land managers.

- **Promote the adoption of interoperable data platforms:** EU policymakers should fully develop Common European Data Spaces to foster interoperability and seamless exchange of high-quality data across agriculture, energy, and environmental sectors. Establishing a common platform for cross-sectoral data integration would provide policymakers with a more comprehensive understanding of land-use dynamics. This platform should offer simplified, user-centric interfaces and prioritise real-time data sharing to enhance decision-making. Inspired by projects like LANDSUPPORT, such platforms should utilise harmonised datasets on soil health, biodiversity, and renewable energy potential to support informed decision-making.

- **Consolidate governance mechanisms for land use optimisation:** The European Union should establish an EU-level task force dedicated to aligning digital tools and policy implementation across sectors. This body would ensure coherence in land use planning and management by addressing policy silos, standardising data-sharing protocols, and facilitating integrated approaches to meet energy, food, and nature restoration objectives simultaneously. Furthermore, it would address data privacy concerns by promoting ethical data usage and devising targeted education campaigns.

- **Develop sector-specific AI guidelines** under the AI Act tailored to the nature restoration, agriculture, and energy sectors. These guidelines should clearly define compliance pathways for potentially high-risk

AI applications in each sector and provide targeted support for smaller developers. Ensuring that these guidelines foster data interoperability, enhance access to high-quality datasets, and minimise regulatory burdens will help unlock the full potential of AI technologies for land use optimisation while maintaining the EU's legal and ethical standards.

ENHANCING DIGITAL INFRASTRUCTURE AND SKILLS

- **Funding the transition:** The next CAP budget structure should include funding for the uptake of digital solutions for optimal land management. The EU must increase funding under Horizon Europe and Digital Europe programmes to finance research and innovation, and to improve the uptake of digital solutions. It should promote public-private blended finance models to de-risk investments in sustainable and advanced technologies for land management.

- **Invest in digital infrastructure in rural areas:** The EU and member states should invest strategically through the Digital Europe Programme and CAP to bridge the connectivity gap and spur digital innovation, ensuring that rural households can access reliable digital infrastructure. Closing this gap will empower farmers and local communities to utilise digital tools for land management, thus contributing to sustainable and optimised land use while reducing socio-economic disparities in technology adoption.

- **Launch EU-wide training initiatives:** The European Commission should develop and fund training programs focused on digital literacy and skills for rural populations, leveraging EU-level resources such as Horizon Europe, the CAP, Digital Skills Agenda and the European Social Fund. By equipping farmers and land managers with the necessary skills, these initiatives will reduce socio-economic disparities, enhance the uptake of digital tools, and promote sustainable practices in land use across all member states.

PROMOTING SUSTAINABLE PRACTICES AND INNOVATION IN LAND USE

- **Promote the development and use of digital tools that foster mixed-use land management strategies:** The EU should increase funding for research on digital tools such as AI-driven simulation, digital twin technology, spatial analysis and data integration models that enable the implementation of mixed-use strategies for land sharing, such as agrivoltaics and agroforestry, optimising land use for both energy generation, nature conservation and food production. When sustainably implemented, these strategies have been proven to reduce competition for land while safeguarding rural livelihoods.

- **Incentivise precision agriculture technologies:** Member states should provide targeted subsidies through CAP to support the adoption of precision agriculture technologies. These technologies can reduce the overall demand for arable land, enhance resource efficiency, and enable integrated solutions such as Agri-PV systems, which combine solar energy generation with agricultural production, minimising trade-offs between energy and food production.

- **Invest in research on digital bioinformatics tools for innovative protein production technologies:** EU institutions should mobilise public investment to support open-access research on AI-powered bioinformatics tools and data digitisation to enable projects like those by Solar Foods and Farmless (see Section 2.2) to reach scale and demonstrate the potential for optimising land use of novel protein production methods. These technologies can decouple food production from traditional agriculture, significantly reducing the demand for arable land and freeing up resources for energy generation and biodiversity conservation.

ADDRESSING EXTERNALITIES AND SUPPORITNG CIRCULAR ECONOMY

- **Establish enforceable sustainability targets and incentives for data centres:** The European Commission should mandate energy consumption and emissions caps for data centres under the AI Act and incentivise resource-efficient digital solutions to address the environmental externalities of digitalisation. Establishing enforceable targets and financial incentives will ensure that the benefits of digital tools for land use are not offset by their environmental footprint, aligning digitalisation with the European Green Deal's objectives.

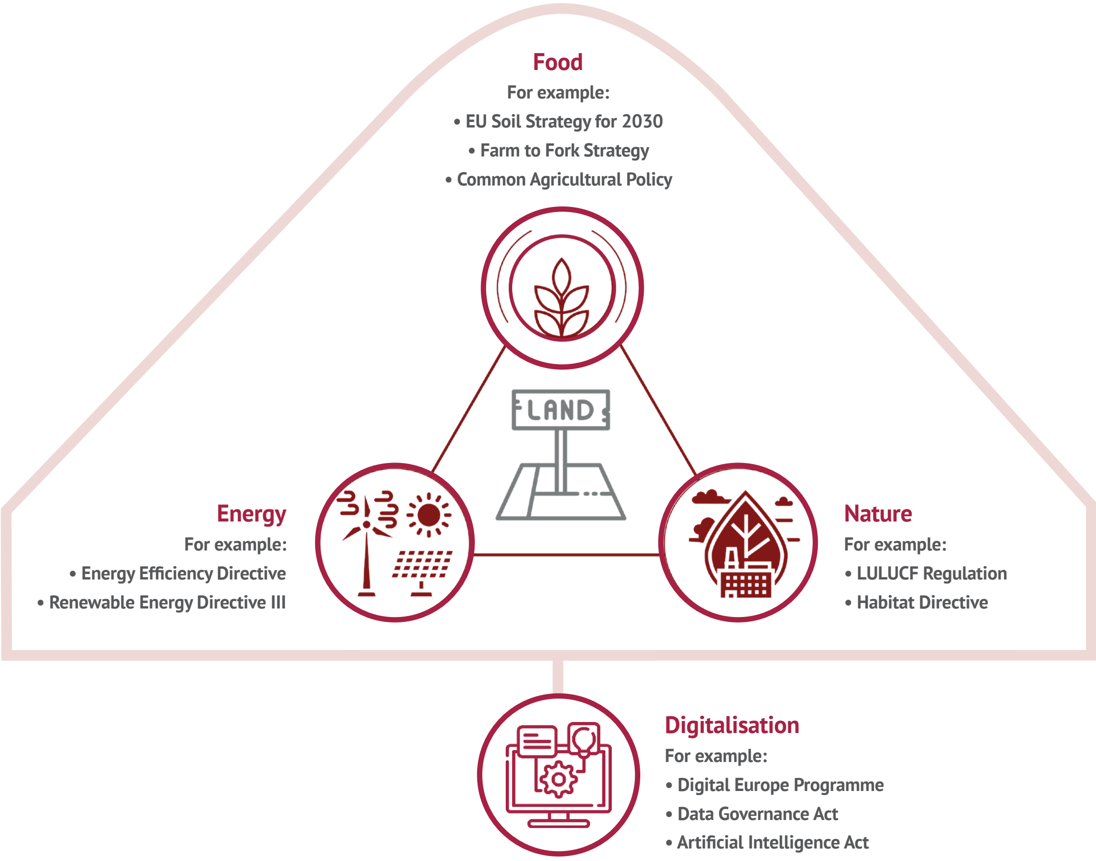
- **Advance the circular economy in the IT sector:** The European Union should finalise the eco-design requirements to make electronics more durable and require manufacturers to incorporate a minimum percentage of recycled materials in their products. This measure will reduce e-waste and mitigate the environmental impact of digital technologies.

- **Facilitate public-private partnerships for IoT solutions:** EU and member state governments should encourage collaboration between public institutions and private companies to develop affordable digital solutions for farmers and actors involved in nature conservation (e.g. NGOs, rangers). These tools, which provide real-time monitoring of environmental conditions, can enhance sustainable land management and reduce conflicts between agricultural practices and other land uses, such as renewable energy projects or conservation areas.

The recommendations outlined in this paper highlight pathways for the EU to enhance its policy coherence, invest in cross-sectoral collaboration, and harness the power of digital tools for land use planning and management. By fostering the integration of these technologies within existing frameworks, promoting innovative land-use and agri-food strategies, and addressing gaps in funding and capacity, the EU can create a sustainable and viable foundation for resolving competing demands on its land resources.

Figure 1

ENERGY-FOOD-NATURE TRILEMMA IN LAND USE



Annex

Agriculture and Food Policies

- Common Agricultural Policy (CAP)
- Farm to Fork Strategy
- Next Generation EU Fund (as it relates to CAP funding mechanisms)
- EU Soil Strategy for 2030

Energy Policies

- Renewable Energy Directive (RED)
- EU Action Plan on Digitalising the Energy System (2022)
- Energy Efficiency Directive (EED)
- Energy Performance of Buildings Directive (EPBD)
- Connecting Europe Facility (as it relates to digital and energy infrastructure)

Nature and Environment Policies

- Nature Restoration Law
- Biodiversity Strategy 2023
- LULUCF Regulation (Land Use, Land-Use Change, and Forestry)
- Habitat Directive
- Birds Directive (Natura 2000)
- Forest Strategy
- Water Framework Directive

Circular Economy and Resource Use

- Waste Electrical and Electronic Equipment (WEEE) Directive
- Circular Economy Action Plan
- Raw Materials Initiative

Cross-Sectoral Policies and Frameworks

- European Green Deal
- Recovery and Resilience Facility
- Multiannual Financial Framework 2021–2027
- European Innovation Council (EIC)
- Digital Compass: The European Way for the Digital Decade

Digital and Data Policies

- Digital Europe Programme
- Horizon Europe Programme
- European Digital Decade Policy Framework ("Path to the Digital Decade")
- European Data Strategy
- Data Governance Act (DGA)
- Data Act (DA)
- Common European Data Spaces
- Green Deal Data Space
- GreenData4All Initiative
- AI Act

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NOTES

NOTES

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The **Sustainable Prosperity for Europe** (SPfE) Programme explores the foundations and drivers for achieving a sustainable, resilient and competitive European economy.

While the climate crisis is a complex challenge to be addressed, non-action is not an option. Prospering within the planetary boundaries requires rethinking our economic model, including our production and consumption patterns, as well as our energy, mobility and food systems. It requires reducing pollution and being smarter with the resources we have. The SPfE Programme engages in a debate on the needed measures to achieve a fair transition to the world we want. It focuses on areas where working together across the EU can bring significant benefits to the member states, citizens and businesses, and ensure sustainable prosperity within the limits of this planet.

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