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INRAE2030
Building a sustainable future through shared science and innovation

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Foreword

INRAE2030: our roadmap for addressing the challenges related to the agriculture, food and environment of tomorrow

When the French National Research Institute for Agriculture, Food and Environment (INRAE) came into being in January 2020, I made the creation of our new horizon 2030 strategy a priority. The global challenges which concern us are immense and it is essential for the Institute to set out clear and ambitious research priorities in order to meet the food and nutrition security of a population that will exceed 9 billion by 2050, to manage the natural resources that are essential to life (water, earth, air, biodiversity) in a sustainable way, to combat climate change and to support those who are working to achieve sustainable and economically viable transitions.

A shared vision

This first year of sustained strategic reflection has been an important one for the Institute. Work on the 10-year plan has consolidated the merger of two organisations, INRA and IRSTEA, each with its own long history of achievements. It has confirmed their complementary nature and their shared vision for the future and has opened up new research opportunities. In response to the increasing diversity of actors and of those who benefit from research, the ever-growing complexity of the systems we study and the increased demands placed on us by society, I wanted a key feature of the strategy to be openness. This strategic plan has therefore been produced by a collective endeavour drawing on our own internal resources and those of our partners and stakeholders. The Institute's management, working with our scientific management and research support teams, set up a dedicated participatory procedure towards the end of 2019. All the Institute's departments and staff were able to participate through on-line consultations and face-to-face discussions. They provided their views on how the Institute should respond to the current major societal challenges, on how we conduct our scientific work, and on the Institute's operational processes. We asked our partners for their opinions on research priorities, on our national and international positioning, and on the strategic emphasis we place on knowledge transfer, expertise and innovation. An international scientific seminar brought the consultation to a close in autumn 2020 and it was at this point that INRAE's Scientific Advisory Board and Board of Directors made their contributions to the strategy and gave it the green light.

This INRAE2030 strategic plan has been produced during truly exceptional times, as the world has faced a pandemic that has brought vast upheaval into our lives, requiring every one of us to learn to live with new and unfamiliar constraints. Despite this fact, a total of over 2600 members of staff, along with a hundred or so partners, have actively engaged in the

consultation process, enabling us to set out a demanding and ambitious strategy. Those participating have worked on the project throughout the year, demonstrating their readiness to get involved and to envisage a future which has never been less certain. I extend my warmest thanks to them all.

An open plan for all

This is the first strategic plan to be published by INRAE and, given our status as a new major player on the international 'agriculture-food-environment' stage, its appearance has been much anticipated. It is for us to demonstrate that we are worthy of the responsibility we now bear. INRAE2030 sets out the major scientific challenges and ongoing research themes for the Institute. It provides confirmation that our priorities are aligned to the public policies of the ministries that oversee our work.

In a context of globalization, the emergence and circulation of infectious pathogens have given rise to numerous health, economic and socio-political concerns. Interdisciplinary research, critical to understanding and preventing pathogen development, lies at the heart of the Institute's strategic plan. Global health is thus one of our scientific priorities, alongside climate, biodiversity, risks, the agroecological transition, the bioeconomy and the responsible management of resources. Now that the digital revolution enables us to study and understand increasingly complex systems, the contributions of data science and digital technologies are essential to this work.

The thematic directions set out in this INRAE2030 document will now be fine-tuned and turned into actions on the ground as our scientific divisions and research centres apply their strategies and action plans. There will be a specific action plan for the Institute's social and environmental responsibilities. New collaborations at regional, national, European and international scales will also be finalised.

Last, our project would not be future facing if it did not carry the promise of increasing scientific openness. We will show ourselves open to partnerships, innovations and expertise. We will be open in the support we provide for public policy, for debate and co-construction, and for the transitions embarked on in our societies. I am delighted that the strategic plan is shaped by this commitment, reflecting the wishes of those who have contributed to its creation.

Philippe Mauguin
INRAE Chair and CEO

INRAE 2030 ›

5 Five scientific priorities (SPs)

SP 1
Responding to environmental challenges and their associated risks

SP 2
Accelerating agroecological and food transitions while answering socioeconomic challenges

SP 3
Building bioeconomies based on the efficient circular use of resources

SP 4
Promoting a holistic approach to health

SP 5
Facilitating transitions by mobilizing data sciences and digital technologies

3 Three policy priorities (PPs)

PP 1
Placing science, innovation, and expertise at the centre of society-policy dialogue

PP 2
Reinforcing our engagement with academic, European, and international partners

PP 3
Establishing social and environmental responsibility as a common objective

Our objectives

Human populations and the Earth are facing global challenges that have created new research expectations: we must help mitigate and adapt to climate change; increase food and nutrition security; boost human and planetary health; facilitate agricultural transitions; preserve natural resources; restore biodiversity; and both predict and manage risks. In addition, we must address regional issues that affect land use patterns, living conditions and income of farmers, economic competitiveness of businesses, and universal access to healthy and diversified diets.

As a public research institute serving the common good, INRAE has a duty to step up the search for solutions. INRAE is among the world's top 10 public research institutes performing work relevant to the United Nation's Sustainable Development Goals (SDGs[1]). Internationally, INRAE is also the first research organization in terms of number of publications specialized in agricultural, food, and environmental sciences. Working closely with its academic, technical, and socioeconomic partners, public authorities, and everyday citizens, the institute seeks to develop knowledge and make discoveries that serve life, humans, and the Earth by providing impactful research results, expertise, innovation, and public policy support.

Thanks to the diversity of its research teams and scientific partners, INRAE is carrying out targeted research that draws upon basic and applied sciences and uses discipline-specific, interdisciplinary, and transdisciplinary approaches. The institute takes advantage of a network of research infrastructures and experimental units that is unique in Europe.

INRAE is resolutely committed to open and participatory science. The institute is an integral part of France's landscape of research and academics and thus enriches French thematic research alliances and regional relationships. Through its international network, it collaborates with the best research teams in Europe and the world.

In all its research and management work, INRAE is committed to complying with applying a code of ethical practices rooted in responsibility, impartiality, integrity, dignity, and probity. We feel that this approach serves the common good.

INRAE is keen to collaborate with any stakeholders who are working to develop more sustainable agricultural, food production, aquatic, or forestry systems or who are striving to protect the environment and regional dynamism. The institute is making important discoveries and identifying novel solutions in these areas.

These words are more than a goal. They are a commitment.

1. https://www.agenda-2030.fr/

INRAE: an outward-looking, multidisciplinary institute performing targeted research in agricultural, food, and environmental sciences

As we face diverse environmental and societal shifts at regional and global scales, we must promote sustainable development by making optimal use of food systems and, more generally, of land. Food and environmental systems can ensure food and nutritional security and food safety while also improving human health and bolstering environmental, economic, and social sustainability. However, to do so, such systems must undergo radical transformations over the next 10–30 years, via immediate action, progressively applied solutions, and customised transitions.

Several international groups of experts have proposed solutions for bringing about these transformations in ways that would also make it possible to respect the Earth's limitations, keep global warming below +2°C by 2100, and sustainably feed up to 10 billion people in 2050, while still boosting the resilience of vulnerable systems and regions. Dedicated to social justice, France's Citizens' Convention on the Climate [2] has come up with 149 potential actions for reducing greenhouse gas emissions by 40% before 2030. Several are specifically focused on the ways in which we feed ourselves, an area of concern previously identified by international scientific bodies that is also one of INRAE's research specialties.

INRAE is a Public Scientific and Technical Research Establishment (EPST) under the joint aegis of the French Ministry of Higher Education, Research, and Innovation (MESRI) and the French Ministry of Agriculture and Food (MAA). The institute performs targeted research, combining fundamental and applied approaches to effectively promote sustainable development. As a public institution serving the needs of society, INRAE collaborates with public authorities, academic and technical research partners, socioeconomic stakeholders, and everyday citizens. It pays minute attention to the direction, development, dissemination, and application of its research, parlaying its discoveries into sound public policy and manifold innovations.

INRAE has the ambition and the responsibility to serve the public interest. The Institute therefore asks for exemplary behavior of its employees, and is committed to providing clear benchmarks (Charter [3] institutional policies on scientific integrity [4], and the Joint INRAE-CIRAD-IFREMER-IRD Ethics Advisory Committee [5]) so that everyone can place, at the heart of its missions and activities, the ambition to serve the general interest in an impartial and exemplary manner.

By encouraging research at the forefront of knowledge, INRAE cultivates a wide and rich range of disciplines including life sciences, health and environment, earth sciences, engineering sciences, mathematics and digital, physics and chemistry, as well as human and social sciences. These disciplines and their scientific communities are supported, mobilized and coordinated within 14 research divisions [6]. In addition, collaboration across divisions and disciplines is fostered by science foresight studies [7] and metaprogrammes [8]. The institute also draws upon the diverse forms of technological expertise found within its experimental units and research infrastructures [9]. The latter are often jointly managed with other public research organizations and are part of French and/or European roadmaps.

2. https://www.conventioncitoyennepourleclimat.fr/en/
3. https://www.inrae.fr/sites/default/files/pdf/Charte-Deontologie_INRAE-%5BUk%5D-Pages.pdf
4. https://www.inrae.fr/sites/default/files/pdf/POLITIQUE_SCIENTIFIQUE%2006012021.pdf
5. https://www.inrae.fr/en/ethics-committee
6. https://www.inrae.fr/en/about-us/organisation
7. https://www.inrae.fr/en/interdisciplinary-scientific-foresight-studies-clarifying-our-goals
8. https://www.inrae.fr/en/about-us/metaprogrammes
9. https://www.inrae.fr/en/research-infrastructures-inrae

INRAE has 18 research centres [10] located in mainland France, Corsica, and further abroad (i.e., the French West Indies and French Guiana). At each of its locations, the institute actively contributes to higher education, research, and innovation through partnerships with universities, technical universities and engineering schools, and local stakeholders in the public and private sectors. INRAE has also developed bilateral and multilateral collaborations with many other national research institutes, notably members of Agreenium [11] and the five French thematic research alliances [12]. INRAE thus establishes joint strategic priorities with its academic partners at major regional sites and, together, they invest resources to bolster site research, training, attractiveness, and impact. At the same time, the institute is building connections with local and national socioeconomic partners by promoting inter- and transdisciplinary approaches and by working with diverse stakeholders (e.g., farmer organizations, non-profit organizations, small- and medium-sized enterprises, intermediate-sized enterprises, large companies, cooperatives, ministries, government agencies, technical institutes, industry representatives, local authorities). Consequently, INRAE is highly proactive in promoting open, participatory scientific approaches and exchanges.

INRAE's work extends beyond France. The institute and its researchers contribute to public policy via international fora associated with the United Nations, the OECD, and the European Union, providing knowledge and expertise that help further develop the science behind integrated diagnostics, evaluation methods, and foresight studies. Furthermore, since such multilateral efforts show research gaps, INRAE takes part in joint research programming initiatives to bridge such gaps and contribute to new data through shared infrastructures, notably within Europe. The institute also actively recruits PhD students and young researchers from abroad.

10. https://www.inrae.fr/en/centres
11. https://en.agreenium.fr/
12. https://www.allenvi.fr/allenvi/autres-alliances-de-recherche

Five

scientific priorities
(SPs)

INRAE structures its research around five major scientific priorities (SPs) into which are woven subjects tied to higher education, innovation, and public policy. The challenges associated with each of the SPs require working across different temporal, spatial, and organizational scales; drawing upon a wide range of scientific disciplines; and utilising a variety of approaches (biological, ecological, [bio]technological, organizational, economic, and political).

These SPs should be achievable given current investment in French research and higher education, the European Green Deal, and the Horizon Europe programme. Because we are facing challenges that extend well beyond European borders, the institute is also developing international partnerships, with a focus on low- and middle-income countries, notably those in Africa.

SP1

Responding to environmental challenges and their associated risks

Multiple global changes are currently underway, and some are the result of agricultural and forestry practices. These changes are intensifying many kinds of risks, and their impacts are already being felt in numerous ecosystems and human populations. For the ecological transition to fully succeed, we must identify strategies that both reduce the vulnerability and increase the resilience of agricultural systems, food production systems, human populations and the environment.

SP 1.1. Climate change: mitigation and adaptation strategies

We are grappling with climate disruption. INRAE research is thus exploring mitigation strategies that reduce greenhouse gas emissions and boost long-term carbon storage. Mitigation alone will not be sufficient. Therefore, in tandem, we must design and deploy adaptation strategies that account for local conditions and that increase system resilience via several means (e.g., water resources, genetic selection, economic measures). In addition, we must assess the sustainability of the proposed strategies by comparing short- and long-term stresses and considering strategy benefits relative to other facets of global changes. This objective is being pursued by the metaprogramme Regional Adaptation and Mitigation Strategies in Agrifood and Forestry Systems to Deal with Climate Change (STRADA).

SP 1.2. Biodiversity: a powerful tool and a valuable inheritance

Biodiversity helps guarantee resilience in the face of numerous hazards. It is thus a common good that must be protected and, when possible, restored. Environmental conditions are rapidly changing, and it is important to both halt the loss of biodiversity and ensure its sustainable use. Our research aims to understand the different drivers at work and to identify the impacts to be tackled first. In addition, our objective is to ensure that biodiversity is a key consideration in decision-making by stakeholders and government officials. In addition to the research being carried out by INRAE units, the interdisciplinary metaprogramme Biodiversity and Ecosystem Services (BIOSEFAIR) has just been launched in collaboration with two European networks, PEER [13] and ALTER-Net [14], and the European partnership, Rescuing Biodiversity to Safeguard Life on Earth, coordinated by the French Foundation for Biodiversity Research.

SP 1.3. Organismal adaptations: tools for guiding genetic selection and preserving biodiversity

The mechanisms used by living organisms to adapt to environmental conditions can serve as tools for facilitating the ecological transition and responding to diverse, fluctuating, and unpredictable environmental conditions. We are expanding our understanding of how these mechanisms operate at different scales (from individual organisms to entire species) to define the potential for adaptation and thus predict individual phenotypes and the evolutionary dynamics of populations.

SP 1.4. Assessment and management of natural and climatic risks

Numerous natural and climatic risks are worsening. Given their cascading effects on ecosystems and human societies, INRAE is seeking to clarify the underlying causes of these risks under dynamic and unpredictable environmental conditions. This task requires analysing stakeholder perspectives, points of vulnerability, and the capacities of systems to plan for and adapt to change. It is also necessary to gather technical and economic tools and models to guide decision-making, resource management, and regional actions at different time scales.

Genetic resources managed at the Biological Resource Centre (CRB) for small grain cereals.
Unit: Genetics, Diversity and Ecophysiology of Cereals (GDEC)

13. PEER : Partnership for European Environmental Research ; https://www.peer.eu/

14. ALTER-Net : A Long-Term Biodiversity, Ecosystem and Awareness Research Network ; http://www.alter-net.info

Triggering and observation of an avalanche on the Col de Lautaret experimental site
Unit: Torrential Erosion, Snow and Avalanches (ETNA)

Experimental facilities conducting research on treatment and recovery processes for urban wastewater, developing new applications to promote biodiversity and contribute to the circular economy.
Goals: making better use of matter and energy, and reusing wastewater.
Unit: Reduce, Reuse, and Recover Wastewater Resources (REVERSAAL)

HIGHLIGHTS

Soils and land use

Soils provide many ecosystem services and are one of the largest reservoirs of biodiversity. Side by side with our partners, we are breaking down soil quality into its various components. We are also developing suitable monitoring tools to perform the following tasks: clarify how these components affect soil functions and services; reveal how these components vary at different spatial and temporal scales; help resolve issues related to land value and use from different cultural, economic, environmental, and regulatory perspectives; and provide tools for sustainably managing this essential resource. INRAE plays a major role in addressing these issues within France (as a member of RNEST[15]), and of GIS Sol), within Europe (as a coordinator of EJP Soil[16]), and at the international level (as a participant in the Global Digital Soil Map Consortium and the FAO's Global Soil Partnership[17] and by preparing an international research consortium on soil carbon).

Forests

We have high expectations for forests in Europe and beyond. We want them to mitigate climate change and balance carbon dioxide emissions; adapt to the consequences of climate change; meet societal needs while protecting biodiversity; and continue to provide their host of ecosystem services. Yet, they are under threat. INRAE has contributed to the New EU Forest Strategy and is developing a multifaceted approach that integrates changing societal needs and ecological dynamics. The way in which we manage European forests has effects that ripple beyond our continent, for instance with our research lab in French Guiana, and across the world.

Water resources and inland aquatic ecosystems

The preservation of water resources and aquatic ecosystems is a major concern worldwide, including in France. INRAE partners with environmental managers (e.g., the French Biodiversity Agency [OFB][18], agencies for water resources) to conduct research on all water-related processes, from raindrops hitting the ground to rivers flowing across the land to the sea. We scrutinize both qualitative and quantitative factors: the functional role of water in forest and agricultural ecosystems; the functional role of biodiversity and soil health in the resilience and sustainability of aquatic ecosystems; how land use affects water flows and aquatic systems and the resulting risks; the integrated management of water resources and aquatic biodiversity; and the support needed to facilitate transitions that will promote the preservation and restoration of both.

15. French National Network for Soil Scientific and Technical Expertise
16. European Joint Programme on Agricultural Soil Management: https://projects.au.dk/ejpsoil/
17. http://www.fao.org/global-soil-partnership/about/why-the-partnership/en/
18. https://ofb.gouv.fr

SP2

Accelerating agroecological and food transitions while answering socioeconomic challenges

An in-depth redesign of agricultural and food production systems is required to meet food demand, with safe, healthy and sustainable food, by reducing negative environmental and health impacts of production, increasing food system resilience to global changes, improving the autonomy of territories and answering socioeconomic challenges. To this end, more holistic research is needed bringing together sustainable production and responsible consumption principles.

SP 2.1. An exploration of transitions and obstacles to autonomy

To address impediments to autonomy and resilience, INRAE is carrying out long-term integrated analyses of how supply and demand respond to the risks and disturbances associated with current transitions. These analyses are exploring interactions at many scales (e.g., farms, regions, individual European countries, Europe as a whole, and other major regions of the world). We want to clarify the factors driving and preventing various stakeholders from adopting new forms of production and consumption. Furthermore, we are investigating economic and social determinants as well as the processes, tools, and public policies that shape the directions taken by agricultural and food production systems.

SP 2.2. Agricultural systems free from synthetic pesticides

We must rebuild cropping systems from the ground up if we wish to dramatically reduce pesticide use while simultaneously maintaining the livelihoods of farmers and product affordability for consumers. The French government has tasked INRAE with running a priority research programme, Growing and Protecting Crops Differently, which combines the efforts of numerous research teams across several scientific establishments. The European Research Alliance towards a Chemical Pesticide-Free Agriculture [19], has brought together several European countries and research institutions. It will be sending along proposals to the European Commission as part of the European Green Deal. Our research focuses on tools at a diversity of scales, from farms to regions, and examines the continuum from production to processing to distribution. We are also looking at the factors determining production levels, economic performance, and environmental effects.

SP 2.3. Farming transitions

Both intensive and extensive farming systems have negative environmental impacts. They also raise ethical issues related to animal welfare and concerns over the working conditions and income of livestock farmers. Our research seeks to build livestock systems that support animal health, animal welfare, and farmers' quality of life while also generating high-quality, healthy food products. Given current transitions in food consumption and diets, we also recognise the importance of capitalising on the nutritional, environmental, and societal services provided by livestock farms, while reducing their negative impacts and ensuring their economic viability.

We are performing interdisciplinary work on these topics via the metaprogramme Farm Animal Health and Welfare (SANBA), and we run a regional innovation laboratory *(LIT Ouest Territoires d'Elevage)*, which brings together all types of stakeholders, including farmers, consumers, and everyday citizens.

Apple harvest.
The Gotheron Experimental Unit conducts research programmes on sustainable production systems in fruit arboriculture
Gotheron Experimental Unit for Integrated Research (UERI)

19. https://www.era-pesticidefree.eu/

SP 2.4. Creation of high-quality diets

We need to rethink the relationships among agricultural production and food processing, distribution, and consumption. As dietary shifts boost agroecological farming practices, we will need to change how we gather, store, process, formulate, and preserve food. It will also be necessary to update current marketing methods. For example, to increase protein and nitrogen autonomy, we need tools that will allow us to better exploit nitrogen fixation by symbionts as we develop protein-rich plants for human consumption. INRAE research is revisiting how the characteristics of food are constructed by working on processing and production methods in tandem, from farm to fork and fork to farm, and by integrating issues related to system competitiveness and both the expectations of consumers and the general public.

SP 2.5. Healthy, sustainable, accessible, and satisfying food for all

The prices of agricultural supplies and food products are coming under increased pressure due to population growth, environmental regulations, international exchanges, global trade, and disruptions in supply chains due to climate change and health crises. We are facing major threats to food autonomy and security. INRAE research focuses on innovation pathways; organizational structures; system location, diversity, and coexistence; food price dynamics; market operations; and the distribution of value within industries. We analyse and evaluate policies related to agriculture and food production as well as the interactions of such policies with trade policies, environmental policies, and corporate strategies. The goal is to forecast the consequences, synergies, and stresses arising from interactions among public policy objectives, stakeholder priorities, and decision-making hierarchies.

(left)
Field trial of soft wheat in organic agriculture. Unit: Institute for Genetics, Environment and Plant Protection (IGEPP)

(right)
A flock of Romane sheep grazing outside all year on La Fage Experimental Farm.

HIGHLIGHTS

Shifts in scale for organic farming

Demand for organic food products is growing, and both the European Green Deal and the French programme *Ambition Bio* are aiming for 25% organic agricultural production in Europe by 2030. INRAE is identifying the conditions that must be met for this large-scale transition to occur. The institute is also trying to predict its effects on farms, regions, industries, and markets. The metaprogramme Scaling Up Organic Agriculture (METABIO) is taking a systemic and interdisciplinary approach to 1) explore the balance among environmental, health, nutritional, economic, and social objectives; 2) investigate resource utilisation and the adoption of farming practices; and 3) characterise interactions between different agricultural and food models against the backdrop of the agroecological transition.

Updates to the Common Agricultural Policy

We are developing our skills and expertise to help achieve the environmental and climate goals of the European Green Deal. We are exploring issues related to agricultural and food production systems using a farm-to-fork perspective with a view to updating the Common Agricultural Policy and developing functional tools[20]. INRAE research is looking for answers to the following questions: 1) How do we holistically approach food systems to boost sustainability? 2) How do we build solidarity among Member States despite their country-specific versions of European legislation? and 3) How do we concretely facilitate the necessary transition to sustainable systems while guaranteeing the livelihoods of European farmers and supporting agriculture in the Global South?

20. Détang-Dessendre C., Guyomard H. (Coord). (2020). Quelle politique agricole commune demain ? Versailles, Editions Quae, 306 p.

SP3

Building bioeconomies based on the efficient circular use of resources

Sustainable bioeconomies establish new approaches to resource use: renewable carbon sources replace fossil fuels in the production of food, energy, chemicals, and basic materials, and the use of water, carbon, nitrogen, and phosphorus is more efficiently managed. The combined result is a reduction in overall environmental impacts. Such bioeconomies also give rise to new value chains, markets, and stakeholders. These generate risks, which must be assessed and managed.

These issues exist at multiple scales, from local to global. Ecosystem services, consumer needs and uses, and system vulnerability are all scale dependent. An important concern is the stressors associated with global changes, notably climate change. The metaprogramme Bioeconomy for Urban Territories (BETTER) is carrying out interdisciplinary research on the challenges associated with the bioeconomy transition, notably those related to technological and organizational innovations. More specifically, researchers are examining the relationships of cities with the more or less distant regions that supply their food.

SP 3.1. Carbon, nitrogen, and phosphorus cycles in terrestrial ecosystems

To use biomass and organic products more efficiently, including wastes, we must better quantify material flows, potential production, potential intensification, and the resulting environmental impacts. It is also necessary to improve our assessments of the economic value of environmental services to assess possible trade-offs. Our research aims to close biogeochemical cycles, particularly for nitrogen and phosphorus, while also preserving stoichiometric ratios with carbon and strengthening coupling among multiple cycles (including the water cycle).

SP 3.2. Water cycles - relationships large and small

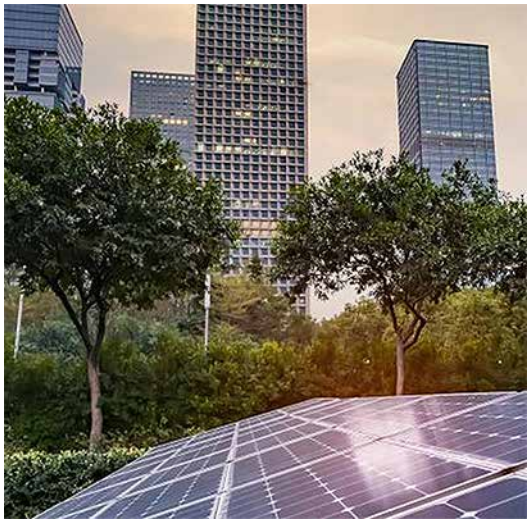
The water cycle, hydrological regimes, and aquatic ecosystems are affected by global change as well as by local pressures, such as changing land use. INRAE research is exploring these effects, including those involving vegetation cover at the watershed scale and beyond. Our objective is to improve our understanding of the water cycle's components, their variability, and their interactions. The institute is studying how to improve water use efficiency - balancing the needs of urban, agricultural, and industrial systems with those of aquatic ecosystems. We are looking at water quality, the potential to exploit untapped resources (e.g., treated wastewater), and short- and long-term strategies for managing ever-more-frequent water crises.

SP 3.3. Treatment and usage of biomass, by-products, wastewater, and organic residues

Biomass can be used to create a wide range of food and non-food products. However, we must first design effective tools for processing biomass resources, which present challenges because of their low energy content, low carbon density, complexity, diversity, heterogeneity, and seasonality. INRAE is thus investigating how to develop processes that are efficient, customisable, robust, and low risk (e.g. from a chemical, ecotoxicological, and/or technological perspective). We are examining resource use efficiency across the supply chain and exploring techniques for limiting loss and waste at several scales (e.g., of a production site or a region).

SP 3.4. Biobased products: developing new market relationships and social dynamics

INRAE has taken on the important task of developing markets for non-edible biobased products, progressing with care to build confidence and limit the risks to industries and consumers. Bioeconomy value chains must become more economically attractive than fossil fuel value chains. In a context where it is crucial to ensure food security, there are numerous sources of uncertainty: variability in biomass supply, price volatility, and the risks inherent to innovation development. Furthermore, innovations give rise to social controversies.



Bioeconomy in urban territories
Reconciling the development of cities with their environment
© AdobeStock

Plastic
© AdobeStock

HIGHLIGHTS

Renewable energy sources

INRAE is exploring multiple pathways for reducing the dependence of food systems on fossil fuels. Potential solutions include agricultural photovoltaics, heating systems that use locally produced biogas, improvements in cold-chain energy consumption, energy-efficient processing technologies, and systems for exploiting biomass as renewable energy that do not compete with food production or interfere with climate change mitigation.

Plastics

The environment is becoming polluted with petroleum-based plastics and the microplastics they generate upon fragmentation. However, at present, bioplastics remain an imperfect solution. First, they are expensive. Second, bioplastic production and food production compete for the same raw agricultural materials. Third, they are generally only biodegradable under industrial conditions. INRAE is seeking to reduce the use of plastics in agricultural and food production systems. However, recognising they will remain necessary in certain situations, the institute is also designing bioplastics made from waste materials that have low environmental impacts over their lifetimes and that are fully biodegradable in nature. Non-biodegradable plastics remain widely used and are omnipresent. We are studying their dispersal patterns, their fate, and their impacts on health and the environment. We are also developing procedures for fully recycling such plastics.

SP4

Promoting a holistic approach to health

Global warming and the expanding ranges of pathogen vectors contribute to spread emerging plant, animal, and human diseases across Europe and the world. Chemical substances, including medicinal compounds, are used in agricultural systems. They then end up in the environment, feed, and/or food, where they can adversely affect biodiversity as well as human and animal health. Factors that contribute to global warming and environmental degradation include dietary imbalances, which are directly associated with the prevalence of the triple burden of malnutrition (overnutrition, undernutrition, and micronutrient deficiencies) and of many diseases.

The relationships among food production, the environment, and health are therefore key issues being addressed by INRAE as it investigates food system transitions and environmental preservation. Our work takes a specific tack: we use the transversal and integrative approach embodied by the EcoHealth concept [21].

SP 4.1. Emerging and re-emerging infectious diseases that move within and among environments, agricultural systems, and food production systems

Epidemics result from a variety of causes: deforestation, agricultural practices, urbanisation, the loss of biodiversity, and the expansion of international transportation networks. All these phenomena offer pathogens new opportunities to come into contact with plant species, animal species, and human populations. The COVID-19 pandemic has illustrated the impact that such zoonoses can have on human health, the economy, and societal dynamics. Our research must identify environmentally friendly practices that effectively prevent pathogen emergence. This work involves reconsidering our relationship with biodiversity and recognising the ties between the social and ecological dimensions of emergent diseases.

SP 4.2. Pollution, contaminants, and the exposome [22]

Food systems are the source of multiple types of chemical pollution. When such pollutants mix with pollutants of other origins, ecosystems and public health are dramatically affected. In this domain, INRAE faces a variety of research challenges: characterising these pollutants; quantifying exposure to contaminant cocktails (which often occur in trace amounts); assessing the threats posed to biodiversity and to organismal health at all life stages; and predicting and managing the risks of exposure.

Against this backdrop, dealing with antibiotic resistance remains a global public health issue, and it requires us to address human, animal, and environmental facets in tandem. INRAE is developing its research in this domain both within France, via a priority research programme [23], and within Europe.

SP 4.3. Preventive nutrition for improved human and environmental health

To simultaneously attain objectives related to public health and environmental preservation, we must better assess the impacts of supply, demand, and the environments in which food is produced. To this end, INRAE research on dietary impacts examines the wide range of production, processing, storage, and distribution methods. Furthermore, with a view to designing effective nutrition-related policies that help preserve human and environmental health, we are exploring how dietary needs vary depending on age, physiological condition, and physical activity while simultaneously addressing the environmental impacts of human diets and accounting for the local, cultural, and economic contexts in which individuals live. The metaprogramme Agrifood Systems and Human Health (SYALSA) develops interdisciplinary research in this field.

21. Morand, S., Guégan, J.-F., Laurans, Y. (2020). De One Health à Ecohealth, cartographie du chantier inachevé de l'intégration des santés humaine, animale et environnementale. Iddri, Décryptage N°04/20.

22. The **exposome** is the sum of all the exposures to environmental (i.e., non-genetic) factors that an organism experiences from the time of conception to the end of life; the effects of the exposome and the genome are complementary

23. https://solidarites-sante.gouv.fr/actualites/presse/communiques-de-presse/article/coup-d-envoi-du-programme-prioritaire-de-recherche-sur-l-antibioresistance-429001

Family meal

The result of several years of research, this baguette contains plant fibres selected for their beneficial effects on the microbiota (MICA).

HIGHLIGHTS

Epidemiological surveillance

To better predict and manage health crises, it is important to establish general epidemiological monitoring programmes - that include the environment, animal populations, plant populations, and human populations - as well as location-specific programmes. This work requires improved collaboration among regions and countries, which is a major challenge. INRAE has taken several complementary actions in this domain, including the following:

- To adopt a more holistic approach to health, we are creating three national platforms for epidemiological surveillance, animal health, plant health, and food-chain monitoring; they will be jointly run with ANSES and MAA with a view to promoting database interoperability and work centralisation
- At the 2021 One Planet Summit dedicated to biodiversity, we launched PREZODE, an international programme for preventing the risks of zoonotic emergencies and pandemics[24]; the programme was established under the joint aegis of MESRI and the French Ministry of Europe and Foreign Affairs (MEAE) and in collaboration with several national and international partners
- As part of a partnership with Beijing University, we have established tree plantations in China and France that serve as sentinels for potential insect invasions

Microbiotas - our health allies

Omnipresent in agricultural and food production systems, microbiomes[25] and holobionts[26] form complex networks and systems that interact with the environment. INRAE is performing cutting-edge research and developing numerous innovations with the objective of characterising, understanding, predicting, and controlling the functioning of such microbial networks and flows in various agricultural, food production, and environmental contexts. Such work will help address EcoHealth-related challenges, improve sustainability, and boost the resilience of food systems. We are also looking at how the biodiversity and equilibria of microbial ecosystems are shaped by environmental changes, agricultural practices, and agrifood practices, which all have cascading effects.

24. https://www.inrae.fr/en/news/one-planet-summit-launch-prezode-first-ever-international-initiative-prevent-future-pandemics

25. **Microbiome:** a community of microorganisms (the microbiota) and their activities in a particular setting (e.g., in the presence of specific structural elements, metabolites, environmental conditions)

26. **Holobiont:** a host (animal, plant, human) and all its associated microorganisms

SP5

Facilitating transitions by mobilizing data sciences and digital technologie

Data sciences and digital technologies have given rise to scientific, technological, and methodological advances by allowing deeper exploration of the overarching complexity and diversity of food production and environmental systems; we can now examine such systems on multiple scales, accounting for their evolutionary dynamics. In addition to its analytical, observational, and experimental approaches, INRAE has adopted *in silico* methods of modelling and simulation, computational statistics, and artificial intelligence to assess, design, and control systems of interest.

We are also using digital technologies for transforming these systems. This work has uncovered new research challenges and has brought different innovation frameworks to the forefront, both because of technological innovations and because of the impacts on stakeholder relationships. To this end, we are coordinating a project promoting regional innovation - Occitanum [27] - which is funded by the French Investments for the Future Programme. Bringing together 49 collaborators from the public and private sectors, the programme is using digital technologies and open innovation to facilitate the agroecological transition in the French administrative region of Occitanie.

SP 5.1. Complex and mutable systems

INRAE's scientific priorities seek to parlay diverse and heterogeneous knowledge and data [28] various study systems, which change constantly, face constraints, display uncertainty, and affect diverse stakeholders. We must therefore develop and adapt approaches that will allow us to integrate massive quantities of information, perform data-intensive computing, use machine learning, and carry out models and simulations.

SP 5.2. Sensors and data acquisition systems

Sensor-based data acquisition systems are becoming increasingly efficient as their size diminishes and their portability and versatility increase. They can also be used in ever more diverse ways and contexts, including as part of portable devices, as components of more permanent field set-ups, or attached to gear, drones, or satellites. This technology is booming. Such systems are helping foster research and innovation in the fields of precision agriculture, ecosystem studies, and environmental risk analysis. INRAE is developing sensor technologies and operating methods as well as information systems for managing and processing the resulting data.

SP 5.3. Agricultural equipment for the agroecological transition

Digital technologies allow real-time access to wide-ranging information at various spatial scales that reveals the condition of the environment, crops, and farm animals. This information can then be used, as needed, for instance to guide the management of agroecological interactions within farms. Agricultural equipment is employed to manage living organisms, including crops or farm animals, and varies in nature across systems (e.g., equipment differs for low-input, environmentally friendly systems). Equipment usage is a research topic to be further developed through expanded collaborations.

SP 5.4. Information technologies, networks, and new capabilities

Information technologies have upended the way information is accessed and shared. The magnitude and speed of these processes have been magnified by the COVID-19 pandemic. New information flows are reshaping relationships among stakeholders as well as power dynamics across all food and environmental systems, both locally and globally. INRAE is using an integrated approach to examine how these technologies affect stakeholder practices and their interactions. We are also identifying methods for exploiting digital tools in responsible and relevant ways and more equitably distributing value within food systems.

27. https://occitanum.fr/

28. Here, we are using a broad definition of the term "data". It includes but is not limited to classical digital information, images, digital video or audio recordings, source codes, and workflow analyses.

Visit to the Melgueil Experimental Farm. The DiaScope Experimental Unit studies and observes the diversity of plants (and biodiversity in general) and their capacity to adapt to diverse environments. Mathematics, Informatics and Statistics for the Environment and Agronomy Unit

HIGHLIGHTS

Digital biology: exploring and predicting life

A promising new discipline, digital biology[29] is deciphering the major functions and mechanisms of living organisms and predicting how they will react under multiple fluctuating sets of conditions. Exploring such diverse scenarios is impossible using conventional experimental or observational approaches. The metaprogramme Digital Biology to Explore and Predict Living Organisms (DIGITBIO) is advancing research in this field, helping scientists develop the skills they need to understand and predict the dynamics of biological systems (e.g., in microbes, plants, and animals). This work is taking place at a range of scales - from molecules to whole populations[30] in their local environments - and forecasts how various constraints will affect these systems, making it possible to develop management strategies and action plans. The goal is to monitor biological systems *in silico* by drawing inspiration from the concept of digital twins, adapting it to our specific needs.

High-throughput phenotyping platform of the Ecophysiology of Plants under Environmental Stress Laboratory (LEPSE)

29. Digital biology is a new discipline dedicated to the study of the fundamental computation that occurs during biological processes; it uses intensive computational approaches to analyse data of all types

30. All individuals of a given species found at a given location

Three

policy priorities (PPs)

Three general policy priorities have been established to better orient INRAE research towards the above scientific priorities and to improve living conditions for all.

The first policy priority reflects INRAE's ambitious objective to greatly expand its impacts, by performing work that nourishes research, expertise, innovation, and public policy; by building collaborations with multifarious partners; and by promoting open science. In this way, we are placing the common good and sustainable development front and centre.

The second policy priority strengthens our position and purpose within the academic ecosystem. We must multiply our ties with regional universities, technical universities and engineering schools and, more specifically, develop our site strategies. We must also build and reaffirm relationships with other national research establishments, with European and international counterparts, and with groups working at science-policy interfaces.

The third policy priority emphasises that research flourishes when we work together and provide each other with mutual support as we advance towards our objectives. It also describes INRAE's official strategy for promoting social and environmental responsibility, which unifies and underscores our efforts to promote sustainable development.

PP1

Placing science, innovation, and expertise at the centre of society-policy dialogue

INRAE is tackling major, complex societal challenges that involve a wide range of economic stakeholders, community stakeholders, and public policies. The resulting relationships underpin the innovation process and drive all manner of impacts. We are committed to open science, knowledge sharing, and scientific exchanges with society. Furthermore, INRAE scientists have created a real-time analysis tool, ASIRPArt [31], that researchers can use to visualise and then accelerate or amplify the impacts of a research project or programme at different developmental stages. This investment reflects the institute's full-fledged commitment to fostering innovation and building expertise of all kinds. The end goal is to serve the common good and promote sustainable development.

PP 1.1. Collaborative research that fosters innovation by prioritising collaborative construction and production

We firmly believe in the collaborative creation of value, carried out hand in hand with academic partners, technical R&D institutes, stakeholders from the public and private sectors, and members of the general public. This framework makes our work more effective: we can match our research with the needs of partners and/or entrepreneurs, more rapidly test our discoveries in the field and/or on the market, accelerate knowledge dissemination, and efficiently transform our findings into all types of innovations. We are thus taking new actions to further foster innovation.

PP 1.2. Scientific expertise as a tool for confronting major challenges, encouraging societal exchanges, and informing public policies

Public policies take a systemic approach to environmental and societal shifts [32]. INRAE provides support and expertise to decision-makers, helping them design, evaluate, and guide national and international public policies. In turn, this process provides fodder for the institute's research, leading to new questions, interpretations, and applications. We also intend to ramp up the visibility and degree of expertise we provide to European and global fora and networks, including the European Commission, the United Nations, and their associated expert panels and agencies.

PP 1.3. Open science and shared knowledge

As part of France's national programme to promote open science [33] and in accordance with European and international initiatives, INRAE has constructed a roadmap to accelerate its adoption of open science policies and its sharing of knowledge and data. We are also strongly committed to the further development of participatory research and to dialogues with the third-party research stakeholders. We simultaneously recognise the importance of protecting certain discoveries and innovations: "Science must be as open as possible and as closed as necessary".

Discussion in the field between a farmer implementing soil conservation agriculture and a researcher from the Agroecology Unit.

31. PB Joly, M Matt, DK Robinson. Research impact assessment : from ex post to real-time assessment. Journal of Rsearch and Technology Policy Evaluation, 2019, ffhal-02382425f

32. Examples include the European Water Framework Directive (WFD), Common Agricultural Policy (CAP), the French Law on the Future of Agriculture, Food, and Forestry (LAAF), and the different governmental programmes related to these domains

33. https://www.ouvrirlascience.fr/national-plan-for-open-science-4th-july-2018/

Encounter between the public and researchers on the INRAE stand at the 2020 Paris International Agricultural Show

HIGHLIGHTS

Carnot Institutes

INRAE has partnered with the five Carnot Institutes[34], which offer private companies valuable research at different developmental stages, from pilot projects to prototype testing in the field. Plant2Pro focuses on the agroecological transition in plant production systems. France Futur Elevage explores innovations that can make livestock farming more sustainable and profitable. Qualiment centres its work on food and nutrition in human populations. 3BCAR concentrates on bioenergy, biomolecules, and biomaterials made from renewable carbon sources. Eau et Environnement was created in 2020 and is examining issues related to water management and aquatic ecosystems.

Living laboratories

INRAE is committed to developing new models for open innovation, such as living laboratories, which draw upon local initiatives, experience-based knowledge, resource users, and regional realities. In these laboratories, we share our knowledge, technologies, and methods. We jointly design and test innovations *in situ*. We formulate our research questions based on the needs of diverse stakeholders, who sometimes have conflicting requirements. We thus establish a collection of shared values and aim for innovation transfer that benefits the greatest number of individuals. The institute is a partner in seven regional innovation projects[35], including two that we are coordinating. The aim of this work is to support the ecological, digital, and social transitions of France's regions. We are also working with AAC and ENoLL[36] to build theoretical frameworks for agroecosystem living laboratories.

34. https://www.inrae.fr/en/collaborer/offre-partenariale-thematique

35. These measures seek to feed the innovation potential of regional stakeholders as well as to support and accelerate major transitions. They are action-oriented research tools for bringing together teams of scientists, educators, public stakeholders, private stakeholders, and everyday citizens. They move research and development out of laboratories and into society, introducing innovations into everyday life to gauge their utility; https://www.gouvernement.fr/sites/default/files/document/document/2019/09/dossier_de_presse_-_territoires_dinnovation_-_13.09.2019.pdf

36. https://enoll.org/

PP2

Reinforcing our engagement with academic, European, and international partners

INRAE is strengthening its relationships with key research and academic partners in France, Europe, and the rest of the world. It invests in a few international priority projects of global importance. In this way, we build stronger networks with university campuses and we boost international research collaborations.

PP 2.1. From regional academic ecosystems to national coordination networks

We contribute to the regional structuring of major French university campuses. The goal is to create globally attractive and reputable centres for top quality higher education and research. We contribute to teaching at universities (and other higher education institutions) at more than thirty sites across France [37]. We also work closely with agricultural and veterinary schools, notably those in the Agreenium Alliance [12]. INRAE is moreover supporting scientific coordination among national research organizations: through French thematic research alliances, joint research programming initiatives, and shared national infrastructure.

PP 2.2. Greater visibility and stronger collaborations within Europe

INRAE is committed to helping lead European research on agriculture, food and the environment [38] Thanks to the groundwork laid by the European Green Deal and the new Horizon Europe programme, we will focus our efforts on three lines of action:

- Developing research and building impacts on issues highlighted in the European Green Deal
- Encouraging participation in the major European Commission programmes, collaborative tools, networks, and projects associated with the Horizon Europe framework programme
- Expanding involvement in networks and joint strategic actions (e.g., Joint Programming Initiatives, such as FACCE JPI, the Standing Committee on Agricultural Research [39], the Animal Task Force [40]); structuring bodies (the Bio-based Industries Joint Undertaking [41], EIT Climate-KIC [42], BiodiversA [43]); the initiation of new tasks; and the development of Partnerships within Pillar II of Horizon Europe.

PP 2.3. Leadership in international scientific cooperation

Given the internationalization of research and as a global leader, we are strengthening our outreach and our international engagement. First, INRAE deploys a range of tools to support international scientific cooperation, including framework agreements, international associated laboratories and international research networks. Second, we support incoming and outgoing researcher and doctoral student mobility. Third, we develop international priority programmes aimed at accelerating research on major issues where INRAE has leadership, such as: soils and climate change; agroecology and crop protection; prevention of zoonotic disease emergence; human gut microbiome and health. Moreover, we contribute to the science base of the international agenda by cooperating with UN agencies, UN conventions and summits, as well as with the World Bank and other international organizations.

PP 2.4. Research infrastructures

Digital technologies are multiplying, and analytical technological tools are improving at light speed. There is also a great need to test out novel practices and study living organisms and ecosystems in greater detail. INRAE is thus expanding on its research infrastructure and e-infrastructure policies to boost its competitiveness. We aim to offer public- and private-sector research communities the most effective services available, via partnerships with other French and European infrastructure providers.

37. https://www.inrae.fr/en/centres
38. In 2019, INRAE was number one in Europe in the societal challenge category "food security"
39. *Standing Committee on Agricultural Research:* https://scar-europe.org
40. *Animal Taskforce:* http://animaltaskforce.eu
41. *Bio based industries joint undertaking :* https://www.bbi-europe.eu/about/about-bbi
42. *EIT Climate-KIC:* https://www.climate-kic.org
43. http://www.biodiversa.org/

The 4th World Agroforestry Congress organized by CIRAD and INRAE, in partnership with World Agroforestry, Agropolis International and Montpellier Université d'Excellence. 1,200 participants, from more than 100 countries.

HIGHLIGHTS

Joint projects with CIRAD in Africa
To facilitate shifts in agricultural and food production systems and support measures to protect natural resources in African countries, there must be greater international collaborative efforts made in research and development. In collaboration with CIRAD (specialized in agricultural research for development), INRAE plans to increase our partnerships with African universities and research organizations to jointly design, establish, and operate a research and innovation program focused on key challenges for agriculture, food and environment in African countries.

PP3

Establishing social and environmental responsibility as a common objective

Supporting and sustaining research involves deciding how institutional resources will be used and preserved and how the decision-making process will unfold. This also requires communications with the supervisory ministries and navigating the legal, regulatory, and budgetary rules that shape public action.

PP 3.1. Meaning and identity from social and environmental responsibility

INRAE is committed to developing a clear strategy for promoting social and environmental responsibility (SER) that aligns with its broad scientific strategy as well as its activities, values, and internal practices. To this end, we are measuring and analysing the impacts of our decisions and work on society and the environment. We are striving to bring about change by behaving ethically and transparently, fully complying with current regulations, and accounting for the expectations of internal and external stakeholders.

The SER strategy thus serves as a complement to and extension of INRAE's work on scientific issues related to sustainable development. The strategy is weighty - it combines the principles of shared responsibility, universal participation, solidarity, equity, and efficiency. It is also driven by an ambitious environmental approach employed by all the institute's members (decision-makers, managers, and regular staff).

PP 3.2. A commitment to environmental protection

We must develop ambitious internal policies to promote energy savings, staff mobility, efficient resource use, waste reduction, the preservation of biodiversity, and responsible purchasing decisions. We have come up with an institutional carbon plan for reducing our environmental impacts. It has eight components:

- Responsible work-related travel
- Sustainable energy management
- Improvements in research practices
- Innovative institutional carbon offsetting schemes or the production of carbon credits
- More efficient resource usage and waste recycling
- A commitment to more sustainable purchasing decisions
- More environmentally friendly diets
- Sustainable management of digital technologies

PP 3.3. A dedicated employer

INRAE never rests on its laurels. Having recently received AFNOR's Equality and Diversity at Work certification and the European Commission's HR Excellence in Research Award, the institute is looking to become even more socially responsible. We remain convinced that management styles, the meaning and quality of an individual's work, and the framework and conditions under which work is produced all contribute to the individual development of our personnel and, thus, the collective success of the institute. We are specifically focusing on three areas: improving quality of life at work, fostering digital solidarity, and facilitating mobility within Europe and across the world to enhance research performance.

PP 3.4. A commitment to openness and transparency

Societal expectations are extremely high, and everyday citizens demand clarity regarding how research results and expertise are obtained, the aims of this work, and its timeliness. We are invested in communicating with the general public and teaching members of society about our research. In tandem, we are committed to fostering debate and exchange, especially on high-stakes issues. This commitment means that we must provide space for opposing viewpoints, explore controversial topics, and provide scientific facts to inform debates.

Orientation days for welcoming new staff

Apprentice Researchers at INRAE's French West Indies and French Guiana Research Centre

Glossary

ANSES	French Agency for Food, Environmental and Occupational Health & Safety *(Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail)*
CIRAD	French Agricultural Research Centre for International Development *(Centre de coopération internationale en recherche agronomique pour le développement)*
FAO	Food and Agriculture Organization of the United Nations
IRD	French National Research Institute for Sustainable Development
JPI	Joint programming initiative
MAA	French Ministry of Agriculture and Food
MEAE	French Ministry of Europe and Foreign Affairs
MESRI	French Ministry of Higher Education, Research, and Innovation
OECD	Organisation for Economic Co-operation and Development
SDG	UN Sustainable Development Goal
OFB	French Biodiversity Agency *(Office français de la biodiversité)*
PP	Policy priority
SP	Scientific priority
CAP	Common Agricultural Policy

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