Document de cadrage | **FORESTT**

Programme et Equipements Prioritaires de Recherche sur la Résilience des Forêts (FORESTT)

Priority Research Programme on Forest Resilience (FORESTT)

Strategic Plan - December 2023

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Program acronym	**FORESTT**	
Program title	**FOREST**s and global environmental changes: social-ecological systems in **T**ransition	
Keywords (min 10 – max 15)	Forests, Social-ecological systems, Global change, Forest governance, Bioeconomy, Modeling, Monitoring, Environmental management, Risk management, Ecological dynamics, Adaptation, Mitigation, Forest restoration	
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Pilote institution	INRAE (National Research Institute for Agriculture, Food and the Environment)	
Estimated duration of the program	7 years	
Aide demandée /*Requested funding*	€40,000,000	

TABLE OF CONTENTS

Table des matières

RESUME

FORESTT – Forêts et changements globaux : systèmes socio-écologiques en transition

Les socio-écosystèmes forestiers jouent un rôle déterminant dans les processus d'adaptation et d'atténuation des effets des changements globaux. Toutefois, des menaces majeures pèsent sur le maintien de leurs fonctionnalités socio-économiques, biologiques et écologiques, et les multiples gestionnaires et décideurs sont confrontés à de nombreuses incertitudes. Dans ce contexte, le PEPR dirigé FORESTT propose un programme de recherche ambitieux afin de lever les verrous scientifiques relatifs au fonctionnement multi-échelle des socio-écosystèmes forestiers tempérés et tropicaux, ainsi qu'aux services qu'ils fournissent, à l'évaluation et la gestion des risques, et aux interdépendances, souvent conflictuelles, entre usages et stratégies de gestion à court et long terme. L'ambition de FORESTT est de construire, structurer et d'animer une science forestière interdisciplinaire, participative et transformative, tournée vers l'action et la mise en œuvre de solutions innovantes et pérennes, favorisant la durabilité des socio-écosystèmes forestiers. Pour celà, FORESTT s'appuiera sur une communauté scientifique nationale reconnue pour son excellence et ses nombreux réseaux à l'international, ainsi que sur l'ensemble des parties prenantes du domaine forêt-bois et de la formation. **FORESTT** est structuré autour de quatre grands défis scientifiques, dédiés au renforcement de connaissances dans quatre domaines de recherche prioritaires visant à : (1) relever les défis sociétaux de la transition socio-écologique des forêts, (2) développer une bioéconomie circulaire et agile basée sur le bois et ses dérivés, (3) définir les capacités d'adaptation et de résilience des écosystèmes forestiers afin d'atténuer les effets négatifs des changements globaux, et (4) utiliser des systèmes de surveillance intelligents pour l'appui aux politiques nationales forêt-bois et à la gestion des forêts. Pour répondre à ces quatre défis, FORESTT s'appuiera (i) sur des projets ciblés (au nombre de cinq), prédéfinis en amont et permettant de structurer et renforcer la communauté scientifique nationale autour de priorités répondant aux objectifs généraux du PEPR, et (ii) des projets collaboratifs en support à une communauté scientifique plus large dans

le cadre d'un appel à projets ouvert. **FORESTT** favorisera l'interdisciplinarité autour des sciences sociales et économiques, des sciences écologiques et de l'environnement, des sciences animales et végétales, et des sciences des matériaux, qu'il s'agisse à la fois de la recherche et de la formation. Le programme mettra également en place des structures facilitatrices de l'innovation, ouvertes et co-construites, autour des enjeux sociétaux liés à la gestion et à la planification forestière. Ainsi, **FORESTT** contribuera aux objectifs des stratégies nationales bas-carbone et pour la biodiversité, de la feuille de route forêt de la planification écologique et appuiera la mise en œuvre de la nouvelle stratégie forestière européenne et de la stratégie nationale de lutte contre la déforestation importée. FORESTT vise aussi à fournir des outils opérationnels de concertation, de négociation et d'aide à la décision pour la préservation de la biodiversité et le maintien du bon fonctionnement des écosystèmes forestiers, ainsi que d'accompagnement du développement d'une bioéconomie à haute valeur sociale, économique et environnementale. **FORESTT** capitalisera sur le dynamisme et la diversité de la communauté scientifique française, sur son insertion internationale et sur les atouts de ses dispositifs de recherche sur le territoire métropolitain comme en outre-mer et dans les régions tropicales. FORESTT a pour ambition d'élever le leadership scientifique de la France au plus haut niveau international sur cette thématique stratégique et d'alimenter l'expertise et l'appui aux politiques publiques nationales, européennes et internationales grâce à son ouverture aux porteurs d'enjeux et au déploiement d'actions de transfert de la connaissance.

SUMMARY

FORESTT – Forests and global environmental changes: social ecological systems in transition

Forest social ecological systems play a determinant role in adaptation to global change and mitigation processes. However, managers and decision-makers are faced with many uncertainties due to the major threats to the maintenance of the ecological and social functions of these systems. In this context, FORESTT proposes an ambitious research program addressing the scientific barriers to the multiscale functioning of temperate and tropical forest social ecological systems and the services they provide, the assessment and management of risks relating to global change, and the often-conflicting interdependences between different uses and management strategies in the short and long term. FORESTT aims to build, structure and lead an interdisciplinary, participatory and transformative forest science oriented towards action and the implementation of innovative and sustainable solutions, promoting the sustainability of forest social ecological systems. FORESTT will achieve these goals with support from a national scientific community of recognized excellence, international networks, and the various stakeholders involved in the forest-based sector and training in the field of forest sciences. FORESTT is structured around four scientific challenges dedicated to increasing knowledge and addressing (1) the societal challenges of the social ecological transition of forests, (2) the development of a circular and agile wood-based bioeconomy, (3) the adaptation and resilience of forest ecosystems for mitigating the negative effects of global climate change, and (4) the use of smart monitoring systems to foster scientific discoveries, and to guide forest management and political decisions. Both the already identified focal projects (five in total), structuring and strengthening the national scientific community and focusing efforts on priorities in line with the general objectives of the PEPR, and one open call for collaborative research projects will enable us to address the research objectives defined in these four scientific challenges. FORESTT will promote interdisciplinarity, linking social and economic sciences, environmental sciences, plant and animal sciences, and materials sciences. The program

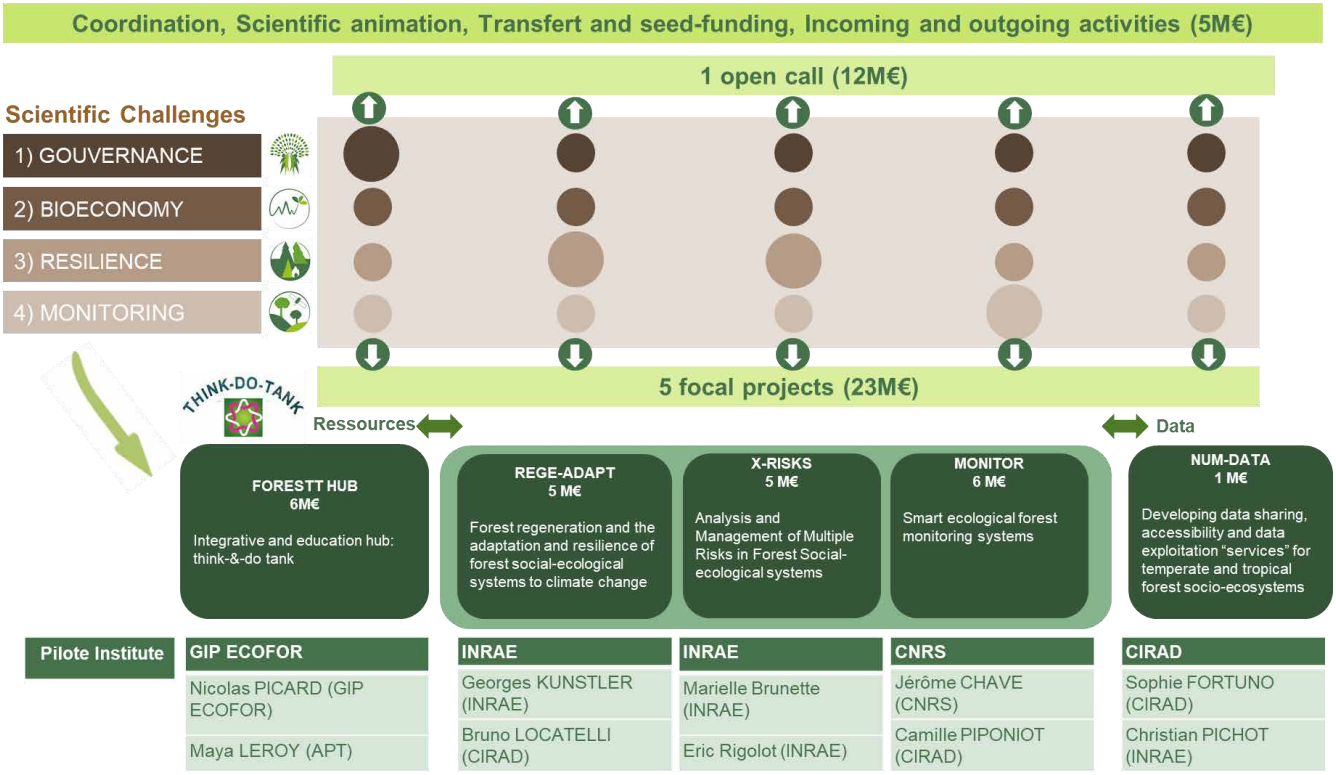
will also establish structures facilitating open and co constructed innovations concerning societal issues relating to forest management and planning. FORESTT will, thus, contribute to the objectives of the national low-carbon and biodiversity strategies, and the “forest” roadmap for the national ecological planning, and will support the implementation of the new European forestry strategy and the national anti-imported deforestation strategy in a context of diversified forest social ecological systems. FORESTT also aims to provide operational tools for negotiation, consultation and decision support for the preservation of biodiversity and maintenance of the correct functioning of forest ecosystems, and support for the development of a bioeconomy of high social, economic, and environmental value. FORESTT will capitalize on the vibrant and diverse French scientific community, with its international insertion and research facilities in France (both mainland France and overseas territories) and in the tropics. FORESTT aims to raise France's scientific leadership to the highest international level for this strategic theme and to provide expertise and support for national, European, and international public policies, by actively seeking contributions from stakeholders and through knowledge transfer.

GRAPHICAL ABSTRACT

The FORESTT program is structured around four scientific challenges (SCs) supported by two types of research project:

- five pre-identified focal projects (FPs) starting in year #1 (2024) ;
- and one open call for collaborative projects starting in year #1.

A third component will ensure the correct coordination, scientific animation, communication and dissemination of the program, the transfer of knowledge into practice and seed-funding to foster partnerships with stakeholders, and incoming and outgoing mobilities. The size of the gray circles in the figure below indicates the extent to which each FP contributes to each SC.



FOREWORD

The FORESTT scientific program has been prepared by a group of scientists from diverse research and education Institutions, at the request of the general secretary for investment (SGPI – France[1]). In response to a letter of commitment sent to the CEO of INRAE, Philippe Mauguin, on January 3rd, 2023, FORESTT proposes a strategic vision for obtaining transformative knowledge-based solutions to accompany the transition of forest social ecological systems toward greater sustainability and resilience.

The proposed program (its scientific priorities and its embodiment in terms of focal projects) was submitted to SGPI on March 1st and was subjected to a series of scientific and strategic evaluations. On September 1st, a dedicated interministerial operational control committee (CPMo) considering the forestry sector and international scientific committee reports recommended the funding of the program subject to revision. On December 4th, the directors of the program provided the CPMo with an updated version **of the programme (this document) as well as the full description of five focal projects** (submitted at an embryonic stage in March 2023). These five focal projects (FPs) were consolidated after an intense period of scientific animation (30 workshops from April to November 2023) serving as a first lever to ensure that the social-ecological approach is collectively embraced and to put the scientific communities (social and natural sciences) on the right track to achieve the desired paradigm shift in the way in which researchers from different disciplines work together.

FORESTT provides scientific support for the national “Forest & Wood'' strategy. In 2022, France launched a huge investment plan for innovation and technological development (€54 billion) – “France 2030” – including ambitious actions for the forest-based sector. As an extension of the Recovery Plan (2021-2022) and in line with the “Sustainable City and Innovative Buildings'' and the “Biobased

[1] SGPI is responsible, under the authority of the Prime Minister, for monitoring the Major Investment Plan and for implementing the Future Investment Program “France 2030”.

products - Sustainable fuels'' acceleration strategies, “France 2030” has two main objectives: (i) promoting the development of the wood-based industry, identified as one of the possible (industrial) solutions for achieving carbon neutrality by 2050 (National Low Carbon Strategy, 2020), and (ii) supporting forest renewal (sustainable management and biodiversity preservation), by optimizing the use of wood resources and enhancing the competitiveness of the wood industry.

As a means of achieving these goals, the French government has already deployed various support programs and calls for projects dedicated to technological developments (pre-maturation, maturation, demonstration and industrialization) for the production of biobased products (sustainable fuels) and the development of innovative processes and products in the construction sector. It has also established a huge financial support scheme for forest renewal and the adaptation of forests to climate change. This "Forest Renewal" program aims to renew 10% of French forests (in the so-called “one billion tree plantation program”) over the next 10 years, through ambitious ecological planning, with funding from both public and private sources.

These actions (summarized in Appendix 1) are based on the view that forest issues are key challenges that must be addressed in the context of ecological transition. Increasing the mitigation potential of the forest-based sector is a national priority[2], but the French government also promotes a proactive strategy for forest adaptation[3] and biodiversity conservation[4], in mainland France, overseas territories and in the tropics[5]. Faced with a rapid increase in tree mortality linked to biotic and abiotic hazards, the government is also strongly focused on risk prevention and crisis management in forests. This strategy will require all stakeholders to be involved and committed to a common dynamic of programming and organizing actions for forests and the wood industry. In 2022, the French Ministry

[2] The National Forest Program (2016-2026) and Strategic contract for the wood industry (2018-2022)

[3] The national program for adaptation to climate change (2018)

[4] The National Strategy for Biodiversity for 2030 (2022)

[5] The national strategy to combat displaced deforestation (2018) and the Alliance for the preservation of tropical rainforests (2020)

of Agriculture established a "Roadmap for the adaptation of forests to climate change" and organized (with the Ministry of Ecology and the Ministry of Industry) a "Forest and Wood Dialog" that brought together almost 500 participants and defined a list of priority actions, one of which was the launch of an ambitious research program dedicated to these forest-related issues.

Within the "directed" part of “France 2030”, in a section entitled "Financing of strategic investments", an action specifically dedicated to funding the most fundamental research is described: the Priority Research Programs and Equipment (PEPR[6]). The aim of this program is to build or consolidate French leadership in scientific fields linked to technological, economic, societal, health or environmental transformation that are considered a matter of priority at national or European level.

In this context, the PEPR FORESTT will contribute to the development of basic scientific knowledge, but it will also provide practical knowledge and decision-support tools to help public and private stakeholders to implement and update the national “Forest & Wood'' strategy. More specifically, FORESTT will provide:

- **Decisive management orientations and silvicultural guidelines** to ensure the successful implementation of the “forest renewal” program, to increase forest resilience and to foster the provision of ecosystem services;
- **Evidence-based information on the state of forest ecosystems and their vulnerability** to multiple hazards, and scenario-based strategies to support risk prevention systems designed by public authorities;
- **Up-to-date and forward-looking knowledge on the availability of raw materials** to help industrial investors anticipate and secure their supply;

[6] The PEPRs have total targeted funding of €3bn and exist in two forms - national acceleration strategy and exploratory PEPRs.

- **Tools for characterizing and evaluating wood product value chains** to guarantee a positive environmental and social impact of the wood-based economy;
- **Innovative governance and management approaches** challenging and supporting implementation of the "Forest & Wood" strategy at the local, regional and national scales.

In collaboration with forest R&D agencies (the ONF and CNPF for public and private owners, respectively) and forest management companies (forest experts, forest cooperatives), the scientific community will help to select and improve reproductive material for forests, develop adaptive management practices and promote ecosystem services. They will, in particular, rely on assistance from the Joint Technology Network on Forest Adaptation (RMT AFORCE) to ensure the transfer of knowledge and the operational implementation of scientific work. FORESTT researchers will also collaborate with the FCBA technological institute and professional organizations (FBF, FBIE, CODIFAB, CSF) to develop a forest bioeconomy making the best use of forest resources and responding to the challenge of decarbonizing the economy. FORESTT will contribute to the development of future forest policy and will provide support to decision-makers involved in the governance of forests and the wood industry. In addition, the FORESTT program will participate – in partnership with universities, the national Agreenium Alliance and engineering schools – in the development of skills in forest social ecological system management, multi-risk approaches, forest monitoring and bioeconomy development. Finally, the FORESTT program will support France in its commitments in favor of the preservation of tropical forests and contribute to the realization of the ambitions of the One Forest Summit held in Libreville in March 2023 and implemented within the One Forest Vision Initiative.

The list of acronyms used throughout the proposal is provided in Appendix 2 and the full list of references is given in Appendix 3.

1. STRATEGIC AND SCIENTIFIC FRAMEWORK OF THE PROGRAM

1.1. CONTEXT, SOCIETAL CHALLENGES AT STAKE AND IMPACTS

The importance of forests for supporting human needs and well-being is now widely acknowledged. Forests are the richest terrestrial ecosystem on Earth and constitute essential habitats for a huge number of species. They are also key elements for water regulation and soil protection. In addition to providing timber and non-wood forest products, forests are important for mitigating climate change and for the renewable energy sector. Human activities and management practices have a major impact on the current and likely future state of the world's forests. There are also intricate links between forests and cultures, social perceptions, and beliefs across the globe. Forest ecosystems are increasingly exposed to unprecedented pressures from global changes, such as climate change and the emergence of pests, and from growing societal demands on natural resources, including new agricultural lands. **Forests are typical examples of social-ecological systems (SES)** resulting from the interdependence between human activities and ecosystem functioning. Engaging the transition of forest SES (FSES) toward sustainability is one of the main objectives of the European Green Deal. However, as witnessed by the debate surrounding the development of the new EU forest strategy[1], the definition of this path gives rise to tensions, raising questions about the nature and mode of compromises required to guarantee both the integrity of forests and maintenance of the services they provide. **The goal of FORESTT is to develop an integrative approach to FSES building, based on scientific disciplines and knowledge integration, to provide matter for debates and decisions on the future of these vital components of the biosphere. FORESTT will involve both conceptual and methodological breakthroughs addressing transformative changes in response to global changes and crises.**

The global and national challenges of FSES require an urgent mobilization of science

FSES play a key role in the four components of global environmental change: global warming[2] and associated extreme weather events, biodiversity and wildlife habitat loss[3], land degradation, and water cycle regulation[3]. They are not only increasingly affected by climate change, but are also largely determined by human activities relating to management practices and land-use changes. The state of forests varies between regions across the world, but, in the face of a global environmental challenge, forest vulnerability should be seen as a worldwide phenomenon.

Forests are major terrestrial biomes, covering 4.06 billion ha, corresponding to 31% of the surface of the Earth. About 1.15 billion ha of forest worldwide are managed primarily for the production of wood and non-wood products and 1.6 billion people worldwide depend directly on forests for food, shelter, energy, medicines and incomes[4]. Forests are a key element of the dynamics of land-use change, and deforestation has led to complex landscape mosaics, within which forest ecosystems have regressed. Over the decade 2010-2020, global forest area decreased by 4.7 million ha per year, this net deforestation rate being lower than in previous decades[5]. However, this balance sheet corresponds to a gross deforestation rate of 13 million ha per year (400 million ha between 1990 and 2020), mostly in the tropics[6], with an expansion of forest area of 5 million ha per year, mostly in temperate zones. Forest degradation, defined as stand alterations not leading to conversion to non-forest land, has become one of the most important processes driving forest carbon loss[7]. Forests are a large terrestrial carbon sink, and, as such, represent an important lever for mitigating greenhouse gas (GHG) emissions[8]. Well-functioning forests are a natural solution to climate change, and must be secured, and even improved, through adaptation to climate change and through mitigation via an effective and sustainable bioeconomy. These questions must also account for transnational interdependencies: land-use changes in one place have long-distance impacts on other functionally connected places not

spatially connected to the original space (see the current debate on displaced deforestation[13]). Similarly, climate regulation by forests requires a science-based, politically committed global approach.

In France, the forested area has increased over the last 150 years, primarily due to the abandonment of agricultural land[9]. In 2019, the forests of mainland France absorbed 50.9 M tonnes of CO_2, 10-20% of France's CO_2 emissions for that year[10]. Forests also contribute to multiple ecosystem services, including, in particular, the ambitious mitigation objectives put forward by the National Low-Carbon Strategy (2020), which plans to dramatically increase carbon sequestration in harvested wood products. However, as highlighted by the parliamentary report produced by member of parliament A.L. Cattelot [11], French forests are currently in crisis. The impacts of climate change and extreme biotic or abiotic events are numerous and already visible[12].

Mainland and overseas French forest ecosystems are highly diversified in terms of composition, functioning and management. Furthermore, the wood-based sector lacks competitiveness, forest ownership is highly fragmented, there are many uncertainties and social expectations are challenging existing management practices. The French government set out to tackle this critical situation, by launching the "Forest and Wood Dialog" in the fall of 2021. The debates highlighted the complexity of forest-related issues and the need for a holistic approach to resolving them.

FSES are exposed to three major types of critical tensions :

● The **supply and demand of services and products,** with an increasing demand for forests to contribute to the supply of wood biomass[14], but also to the storage of carbon and the conservation of biodiversity, often leading to an implicit contradiction between exploitation and conservation;

● **Maintenance of the long-term vitality of forests** given increasing threats linked to global changes, in the form of extreme climatic events, such as droughts, fires of high intensity (mega-fire), insect pest and disease outbreaks, or biological invasions;

● The emergence of controversies on the orientation of forest management and the persistence of conflicts over the use of land and resources challenge **forest governance** (regulatory tools and decision-making methods).

Forests, thus, pose challenges that are both crucial and urgent, and will not be solved with the usual incremental approaches. Through the FORESTT program, we aim to establish and promote interdisciplinary and inclusive forest science as a national priority. This will advance science and foster dialog among stakeholders, facilitating negotiations in an informed pluralistic framework, for the development of **social-ecological long-term transition strategies including four main dimensions**:

(1) A transition to knowledge-based decision-making processes. FORESTT will stimulate the creation of interdisciplinary scientific knowledge and inclusive management actions by mobilizing the national and international scientific community to provide evidence and knowledge-based guidance for global change adaptation and mitigation in line with resilience and sustainability objectives. This will be achieved through the acquisition and dissemination of cutting-edge knowledge, and use of the available knowhow and latest technological developments to characterize the state of FSES and to monitor forest responses to driving factors and stressors, and through the development of interdisciplinary approaches for identifying both operational options for forest management and strategies for forest protection and restoration. Thus, FORESTT aims to provide relevant decision-support tools integrating risk and uncertainty management for both short- and long-term conservation of the functioning and biodiversity of forest ecosystems, while fostering the emergence of a high-value sustainable bioeconomy.

(2) A transition towards a more inclusive governance of forests. FORESTT will help promote dialog between economics and environment, between science and society, and between citizens, private stakeholders, and public decision-makers. It will provide a solid scientific basis for the evaluation and revision of public policies (taking regional specificities into account), particularly in the

context of the implementation of French[14] and European[1] forest strategies and the international agenda relating to UN Sustainable Development Goals, especially SDG #15. It will also strengthen France's influence and leadership in supporting the green transition in Europe and internationally, including in tropical regions.

(3) A transition towards a social-ecological approach to forest management. FORESTT will contribute to the development of new forest management strategies based on a critical analysis of current management practices and doctrines, including those that have often led to trade-off decisions neglecting social-ecological aspects, and foresight and future studies for forests, to meet the challenges of the French roadmap for the adaptation of forests to climate change. It will provide the necessary knowledge for innovations in the restoration and reinforcement of resilience capacities and the adaptation of forest ecosystems, coupling attenuation and adaptation strategies, from a multiscale perspective extending from forest stands to biome, over various time spans, from short- to long-term. It will produce and implement the scientific and technological knowledge necessary to assess the state of forest ecosystems through their ecological, socioeconomic, cultural and technical components, to facilitate prediction of the consequences of hazards and to assess the associated risks. FORESTT will also strengthen French scientific capacities for initiatives for the sustainable management and preservation of tropical forests, thanks to the strong partnership networks CIRAD and IRD have established in these areas (National Strategy to Combat Displaced Deforestation, Alliance for the Preservation of Tropical Rainforests).

(4) A transition towards a forest bioeconomy that performs well economically, socially and environmentally. FORESTT will improve the systemic view of global value chains by strengthening interdisciplinary communities of researchers from forest to wood sciences and extending to environmental sciences, economics, management and social sciences, and research into innovation processes. FORESTT aims to provide socio-technical solutions for the transition of traditional forest-

wood chains to a modern bioeconomy by promoting the insertion of new products (industrial or non-industrial) and services into territorial, national or international markets, while accounting for transnational interdependencies.

1.2. MAPPING OF FRENCH RESEARCH STRENGTHS AND ELEMENTS OF INTERNATIONAL COMPARISON

1.2.1. Mapping of the French FORESTT research community

French sciences dealing with forest social ecological systems are supported by a community of about **1,250 permanent scientists**. The list of national research organizations, higher education and research Institutions, Research-Development & Innovation services in operating organizations is summarized in Appendix 4. The three largest research organizations focusing on forest research are INRAE (250 researchers), CNRS (100) and CIRAD (90)[15]. Universities account for about 370 researchers who contributed to researches on forests and wood.

1.2.2. International positioning of the French scientific community

A first overview of the degree of international involvement is provided by the representation of the positioning of the French community in terms of peer-reviewed publications in the research areas covered by FORESTT. The data were retrieved from the **WoS** by a Boolean search (equation available here[7]) covering a period of 10 years (**2012-2021**). Based on a list of 207,364 articles, France ranks 9th in the world, accounting for 5% of this corpus (Fig. 1a) and 8th regarding tropical forestry research (Fig.

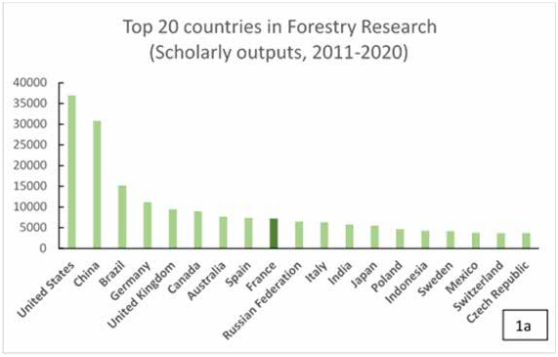
[7] ("*forest*" OR "*wood*") AND ("monitori*" OR "survey*" OR "inventor*" OR "timber*" OR "lumber*" OR "logging" OR "sawmill*" OR "*cellulose*"OR"xylem*" OR "bark*" OR "ligni*" OR "paper*" OR "bioeconom*"OR"material*" OR "*mechanic*" OR "biofuel" OR "civil engineering" OR "preservation" OR "extractible*" OR "tanin*" OR "resin" OR "construction" OR "energ*" OR "chemistr*" OR "cell wall" OR"fibre" OR "machining" OR "drying" OR "glue" OR "bonding" OR "gasification" OR "pyrolysis" OR "combustion"OR "ecolog*" OR "*genetic*" OR "conservation" OR "environment*" OR "silvicult*"OR "resilienc*" OR "breeding"OR "ecosystem services"OR "hazard*"OR"mortality"OR "restoration"OR "dentology"OR "climate change"OR "global change"OR "adaptation" OR "risk*" OR "vulnerability" OR "mitigation" OR "disturbance*" OR "resistance"OR "recovery"OR"biotic"OR "abiotic"OR"dieback"OR"decline") NOT ("galax*" OR "random forest*" OR "phylogene*" OR "cognitive-behavioural"OR" decision tree"OR" *pollutant*"OR" fruit"OR "woodpeckers")

1b). The main disciplinary field covered are by order of contribution Ecology, Forestry, Environmental Sciences, Plant Sciences, Geosciences multidisciplinary, Multidisciplinary Sciences and Soil Sciences (Fig.3) and the main French institutes contributing to this corpus are CNRS, INRAE, CIRAD and IRD (Fig. 2a,b; Fig.4).

This PEPR would approximately double the funding of research on forest social ecological systems over the next eight years, which should enable France to improve its position, with a rank in the top five countries. Focusing only on highly cited[8] papers (*n*=1,951 articles), France ranks 7th and accounts for 13% of the international corpus.

[8] Papers in the top 1% based on the number of citations received relative to other papers published in the same field in the same year.

Figure 1: Top 20 countries in forestry research worldwide (1a) and in tropical forestry research (1b).



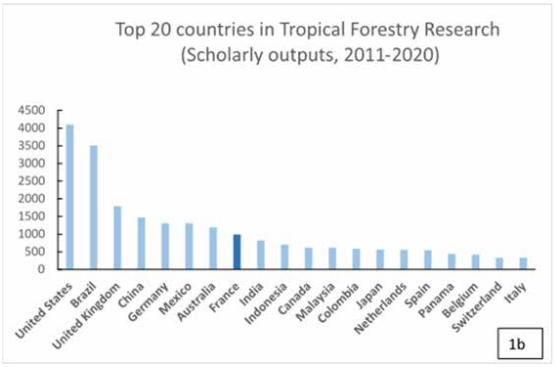
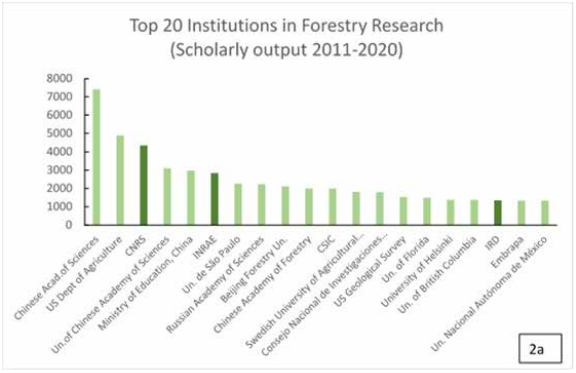


Figure 2: Top 20 research institutions in forestry research worldwide (2a) and in tropical forestry research (2b).



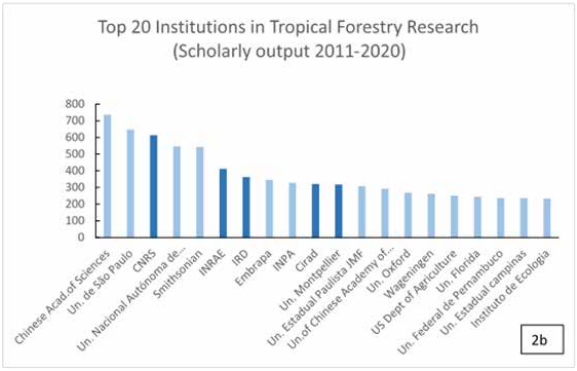
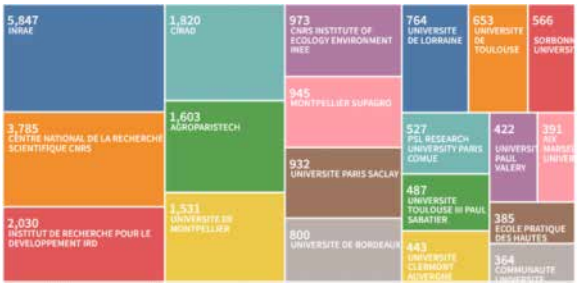


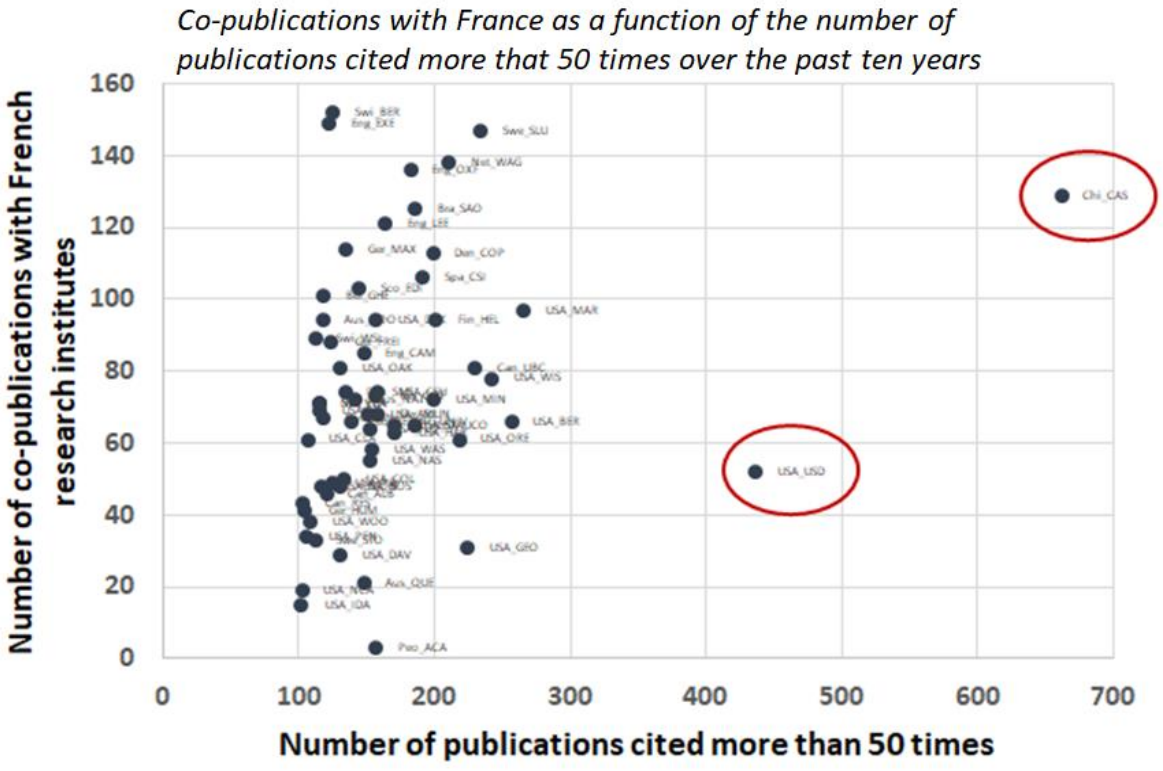
Figure 3: Disciplinary fields for French forest-related publications

Figure 4: Distribution, by institution, of French forest-related publications



We quantified the extent to which France (merging all French research organizations) is connected to other international research institutions, through a bibliometric network analysis (based on co-authorship between institutions) for two datasets: (i) highly cited papers (considering Institutions that have published at least 30 highly cited papers over the study period), and (ii) the most cited (>50 times) publications (*n* = 11,786 references; considering institutes that published at least 100 articles during the period).

The goal of these analyses was to identify major academic partners loosely connected to France for which the international strategy of FORESTT would need to be reinforced. The result (similar for both corpuses) is provided for the second corpus. The figure presented here displays co-publications with France according to the total number of published papers. It shows that France co-publishes with all



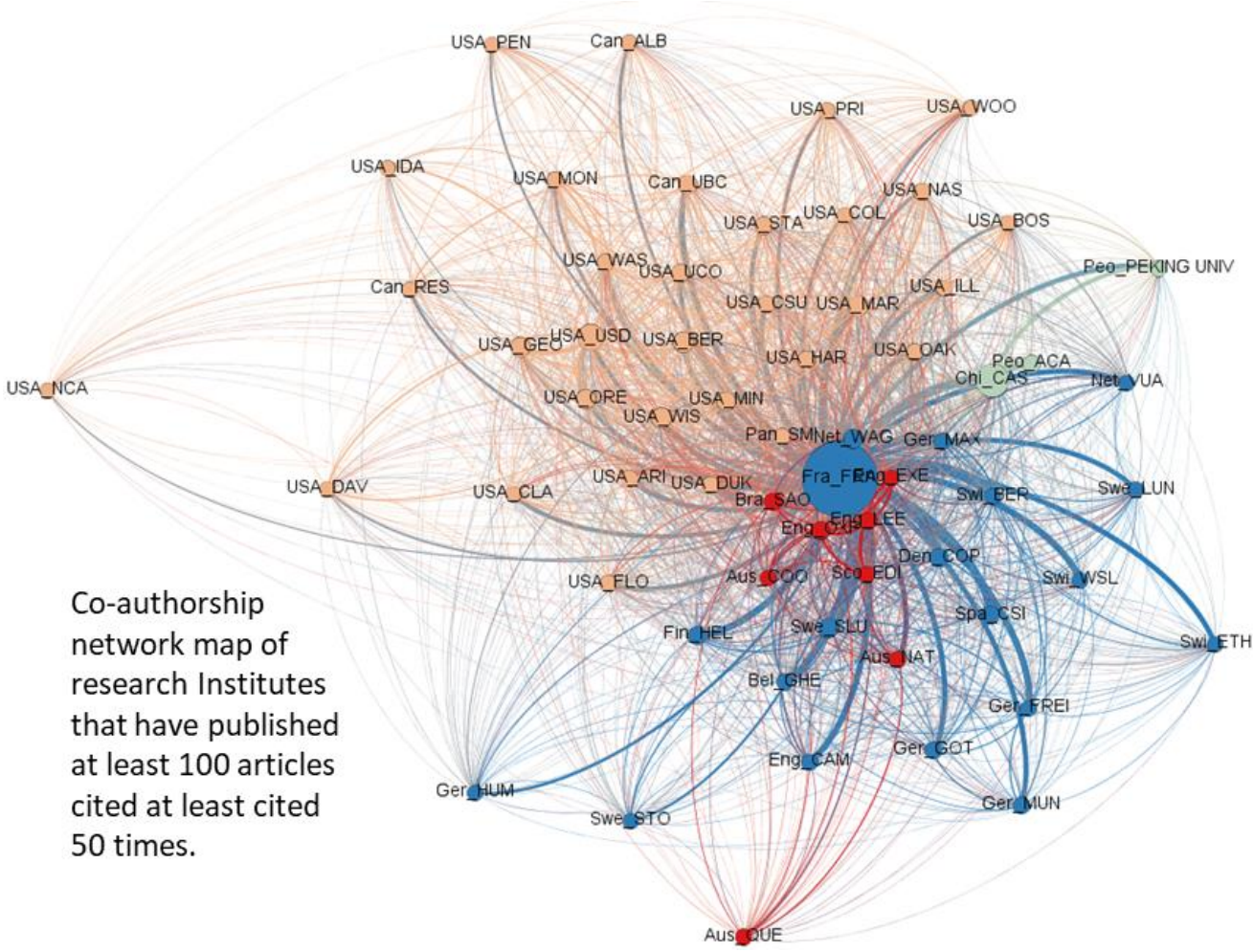
major research institutions in the scientific areas covered by FORESTT. This is clearly illustrated by the almost empty area in the lower right corner.

However, this chart also identifies two outliers (circled in red above): the US Department of Agriculture (USDA) and the Chinese Academy of Science (CAS), two major research institutes in forest research with below-average numbers of co-publications with France. The FORESTT community should identify more precisely the scientific areas demanding particular attention and incentives for encouraging collaboration with the USDA. For CAS, given its leading position worldwide and the significant level of collaboration between France and CAS, continued efforts will be required to maintain (and potentially improve) this encouraging position.

Another perspective is provided by the network of co-authorship between France and international research institutes that have published at least 100 articles (cited more than 50 times) over the last 10 years. The diagram below reveals a highly structured network of collaborations: France (in light blue[9]) is well connected to all its European counterparts, reflecting the structuring force of the European Research Area[10]. US Universities (in orange) also display a high degree of connectivity, and China forms another cluster (light green) that is less connected to the others. A final cluster (in red) comprises the UK, Australian and Brazilian research organizations.

[9] The node for France appears artificially large because all French institutes were merged for the analysis.

[10] As an indication, France has 35% more links within Europe than with US partners.



This analysis confirms that (i) **France has established strong links across Europe** (in particular with SLU in Sweden, Wageningen University in the Netherlands, the Max Planck Institutes in Germany, the University of Copenhagen in Denmark and CSIC in Spain), a situation expected to continue in the framework of the new European research program (Horizon Europe), and (ii) **specific efforts could be made to increase collaboration outside the EU,** particularly with China **(CAS),** the USA **(USDA)** and, to a lesser extent, with Australian Institutes, such as the University of Queensland, James Cook University and the Australian National University, British universities (such as Oxford, Cambridge, Exeter and Leeds University) and the University of São Paulo in Brazil (with which strong collaborations already exist, particularly with CIRAD and IRD). In terms of policy, a PEPR is clearly designed to foster the integration of French research into the European Research Area (ERA). However, FORESTT provides a unique opportunity to strengthen our collaborations outside of Europe too. CIRAD and IRD are

particularly well placed for collaborations with Africa, Southeast Asia, Latin and Central America, the Caribbean, and the Indian Ocean, and these long-standing partnerships will be pursued and reinforced within the context of FORESTT, which will help to catalyze and reinforce this cooperation. As a means of stimulating partnerships with other countries, FORESTT will also leverage on the so-called "International Associated Laboratory[11]" with China[12], Argentina[13], and Canada[14]. Last but not least, with LabEx CEBA, which federates a network of internationally recognized French research teams studying biodiversity in the Amazon, FORESTT is uniquely well-placed to reinforce collaboration with South American countries, particularly through its connections to other partnership instruments in the region, such as IRP CebaCol. France has already long-standing collaborations with Africa on forests and is well-equipped to face the European challenge to foster scientific cooperation with African countries in this field, through the R2Fac network or LMI Dycofac, and the forthcoming vision of the One Forest Summit organized in March 2023 in Libreville (Gabon).

1.2.3. SWOT analysis

We finally use the SWOT framework to identify important assets and problem areas. A summary of this analysis of a comprehensive analysis (Appendix 5) is provided below.

[11] Virtual laboratory bringing together laboratories from INRAE and foreign institutes.

[12] Two joint laboratories: with the Beijing Forestry University on invasive forest pests in Eurasia and with the Beijing Advanced Innovation Center for Tree Breeding by Molecular Design.

[13] **FORESTIA** joint laboratory: "Integrated Study of Adaptation to (A)biotic Stress of Natural and Planted Forests".

[14] FORWARD (FOREST, WOOD, MARKET AND SOCIETY) joint laboratory with Laval University.

STRENGTHS -Excellent and internationally visible scientific community on forest ecosystems and wood science. -Strong centers of forest research connected to forested territories and education. -Research activities addressing a diverse range of forest ecosystems. -A set of research infrastructures registered on the national roadmap and connected to international networks in support of FORESTT activities.	**OPPORTUNITIES** -FORESTT is aligned with national and international political commitments -Horizon Europe should allow the French research community to gain momentum in addressing global challenges. -The French forest research community is already familiar with knowledge integration across disciplines and scales. -Innovative education and training are key assets to foster transformative changes.
WEAKNESSES -French research does not connect environmental, material and humanities and social sciences efficiently. -Research capacities are not evenly spread between disciplines. -The transfer of knowledge and know-how to stakeholders needs to be accelerated.	**THREATS** -The overall national public effort for forest and wood research remains a small percentage of the total value created by the forest and wood sector.

Altogether, these analyses led to the formulation of our vision and of a strategy maximizing strengths and opportunities and minimizing threats and weaknesses (see next section).

1.3. FORESTT SCIENTIFIC VISION AND STRATEGY

SCIENTIFIC VISION: Defining forests as integrative systems entails moving beyond the three pillars of sustainability to ensure that the multiple levels and long-term interdependences between the various dimensions of FSES are accounted for. The principle of multifunctionality associated with the concept of **sustainable forest management (SFM)** is currently being called into question, for two reasons. First, the opposition between economic and environmental/social issues still divides forest managers, stakeholders and policy makers. This situation often leads to conflict and a spatial segregation of forest uses that highlights the difficulties involved in trying to fulfill all forest functions at the scale of a management unit. Second, the principle of multifunctionality stems from a static vision of forest socioeconomic issues and biological processes based on the assumption that the trajectories of forest ecosystem dynamics are predictable, allowing long-term planning. In a context of global environmental

change, this approach is not compatible with the need to consider uncertainty and the need for forests to adapt to rapid climate and societal changes[16]. **FORESTT aims to overcome the SFM vision based on the principle of multifunctionality by promoting a social-ecological approach[17] ensuring that the complexity of the interplay between economic, social and environmental dimensions is integrated into ecosystems trends, rather than each of these elements being considered separately, with possible trade-offs between them.** We therefore need to reconsider the principle of multifunctionality, by analyzing its ecological and land-use planning dimensions, in particular, through the land sparing and land sharing framework. This social-ecological system approach calls for research addressing the spatial and temporal links between ecological systems, economic rationales, social institutions and management practices, with the aim of improving governance and providing decision support. The development and implementation of this approach are currently hampered by (i) a lack of knowledge about the functioning of forest ecosystems in the context of multiple disturbances and uncertainty, complex interactions between the environment and human practices and time- and place-specific factors[18], and (ii) divergences in societal values, interests and the representation of forests, leading to often conflicting interactions between use strategies and practices[19]. If we are to overcome these obstacles, we will need **a detailed and dynamic knowledge of the relationships between human decisions and ecological dynamics, from local to global level**. Forest sciences must also develop a **comprehensive analysis of the temporal and spatial dynamics of interlocking and interdependent ecosystem functionalities, to facilitate the implementation of operational solutions at the multiple scales and dimensions of forest sustainability.** FORESTT will meet these two challenges, by mobilizing disciplinary and cross-disciplinary expertise, developing a **social-ecological approach to forest research (Box 1),** and **fostering transformative changes**. These changes can be implemented and sustained only through negotiations between stakeholders involved in forest use and management, taking into account the practical knowledge of stakeholders. However, they will also require major efforts to train and upgrade the skills of tomorrow's researchers, managers, and decision-makers.

Box 1: The social ecological system approach

The social-ecological system (SES) approach has long been promoted by the scientific community as a means of dealing theoretically and empirically with the spatial and temporal interactions between biophysical systems and socio-economic and political systems [a]. Different conceptual approaches have been developed [b] and experiments have been set up to operationalize these concepts and to promote a holistic treatment of environmental problems [c]. These SES or socio-ecosystem approaches can be used to analyze the anthropogenic and natural pressures on/interactions with ecosystems, and the forms of response implemented by stakeholders to deal with them, with normative objectives that can vary greatly. The solutions proposed and implemented to reinforce the resilience capacity of these systems involve multiple management methods and approaches.

In the forestry sector, the SES approach is used particularly for fire risk management [d], the management and development of forest areas [e], the promotion of recreational services and peri-urban forests [f], and the management of biotic hazards [g]. However, this approach is not yet sufficiently developed in France [h], despite the major perspectives it offers in terms of interdisciplinary research and dialog with stakeholders and public decision-makers. In this context, FORESTT will work on improving formalization of the socio-ecosystem analysis of forests (in temperate and tropical regions) based on the analytical and normative dimensions of the SES approach. The objective is not only to promote a different research-action approach but also to strengthen confidence in science and the legitimacy of knowledge-based decision processes.

Several different conceptual frameworks have been developed and applied to diagnosing interactions and outcomes in SES. This research focuses on understanding many dimensions of system functioning, making it an interdisciplinary field [i] [j]. In FORESTT, we aim to promote this analytical approach to SES studies at project level (starting at the level of each focal project, FP). We therefore support projects that consider different social and ecological variables and interactive processes in forest ecosystem functioning and management. In addition, one workpackage of the FORESTT-HUB FP will be dedicated to the study of socio-ecological changes from a theoretical, conceptual and practical point of view. Finally, over the two waves of open calls, we will solicit and prioritize scientific proposals involving the implementation of SES frameworks and their application to one or more of the living laboratories of the network organized in the FORESTT-HUB FP.

The SES approach also has a normative dimension that aims to guide the governance and management of social-ecological systems to enhance their sustainability [k], resilience [l] or the implementation of adaptive forms of management [m]. This prescriptive issue associated with the SES approach will serve as a support for foresight studies and transdisciplinary research-action activities mobilizing stakeholder participation, particularly within the framework of FORESTT-HUB FP activities.

The SES approach reflects the stance defined in recent forest policy documents. These documents emphasize the need to integrate social, ecological and economic issues into research to meet the challenges posed by global changes (see, for example, the "*Objectif forêt*" report by the "sustainable forest management" specialist committee, drawn up during preparation of the national forest renewal plan, July 2023). They implicitly recognize that social elements (actors and institutions) and ecological elements (ecosystems) interact with each other dynamically within an integrated system. This approach recognizes the interdependence of these elements and, therefore, the relevance of the conceptual framework of the social-ecological system approach. In conclusion, we are convinced that the SES approach (rooted in interdisciplinarity and transdisciplinarity) will improve the

alignment of the PEPR's research program with operational objectives (i.e. moving up the TRL, technology readiness level**,** ladder) and enable us to develop balanced, sustainable solutions, options and trajectories.

[a] Janssen, M. A., & Ostrom, E. (2006). Governing social-ecological systems. Handbook of computational economics, 2, 1465-1509.
[b] Schoon, M., & Van Der Leeuw, S. (2015). The shift toward social-ecological systems perspectives: insights into the human-nature relationship. Natures Sciences Sociétés, 23(2), 166-174.
[c] Bourgeron, P., Kliskey, A., Alessa, L., Loescher, H., Krauze, K., Virapongse, A., & Griffith, D. L. (2018). Understanding large-scale, complex, human–environmental processes: a framework for social-ecological observatories. Frontiers in Ecology and the Environment, 16(S1), S52-S66.
[d] Vigna, I.; Besana, A.; Comino, E.; Pezzoli, A. Application of the Socio-Ecological System Framework to Forest Fire Risk Management: A Systematic Literature Review. Sustainability 2021, 13, 2121. https://doi.org/10.3390/su13042121
[e] Fischer, A. P. (2018). Forest landscapes as social-ecological systems and implications for management. Landscape and Urban Planning, 177, 138-147.
[f] Ferguson, M. D., Giles, G., Ferguson, L. A., Barcelona, R., Evensen, D., Barrows, C., & Leberman, M. (2022). Seeing the forest for the trees: A social-ecological systems approach to managing outdoor recreation visitation in parks and protected areas. Journal of Outdoor Recreation and Tourism, 38, 100473.
[g] Cottrell, S., Mattor, K. M., Morris, J. L., Fettig, C. J., McGrady, P., Maguire, D., ... & Roberts, R. (2020). Adaptive capacity in social–ecological systems: a framework for addressing bark beetle disturbances in natural resource management. Sustainability Science, 15(2), 555-567.
[h] With the exception of the Man-Environment Observatory (CNRS) located in Oyapock, French Guiana and few scientific works: Houballah, M., Cordonnier, T., & Mathias, J. D. (2020). Which infrastructures for which forest function? Analyzing multifunctionality through the social-ecological system framework. *Ecology and Society*, *25*(1).
[i] De Vos, A., Biggs, R., & Preiser, R. (2019). Methods for understanding social-ecological systems: a review of place-based studies. Ecology and society, 24(4).
[j] Partelow, S. (2018). A review of the social-ecological systems framework. Ecology and Society, 23(4).
[k] Abson, D. J., Von Wehrden, H., Baumgärtner, S., Fischer, J., Hanspach, J., Härdtle, W., ... & Walmsley, D. (2014). Ecosystem services as a boundary object for sustainability. Ecological Economics, 103, 29-37.
[l] Grêt-Regamey, A., Huber, S. H., & Huber, R. (2019). Actors' diversity and the resilience of social-ecological systems to global change. Nature Sustainability, 2(4), 290-297.
[m] Findlater, K., Kozak, R., & Hagerman, S. (2022). Difficult climate-adaptive decisions in forests as complex social–ecological systems. Proceedings of the National Academy of Sciences, 119(4)

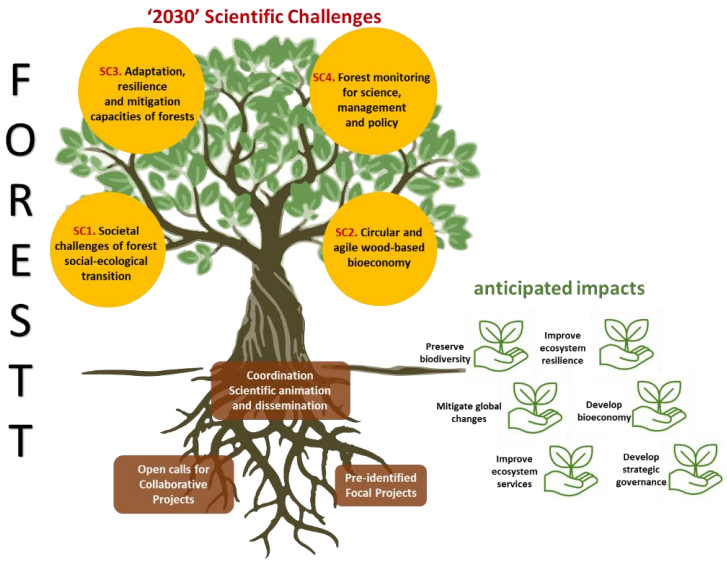
STRATEGY: The FORESTT strategy involves using the strengths of the French research community and correcting its main weaknesses: **(i) to break down boundaries between disciplines and promote social-ecological approaches to forest management.** Managing forests is more than just a technical problem, and scientific evidence is necessary but not sufficient to support decision-making. Indeed, effective forest management requires improvements in the processes of negotiation between diverging interests and the definition of regulatory instruments to deal with uncertainties (*e.g.,* climate change) and heterogeneous situations. It is, therefore, important that forest management practices consider institutions and behaviors, in addition to the conditions under which scientific evidence supports a transformative social-ecological transition of forests. FORESTT, thus, seeks to provide opportunities for cross-disciplinary research to promote the integration of diverse data and disciplinary methods into "interdisciplinary" research, up to the epistemological synthesis to which "transdisciplinary" research aspires, and which should provide a problem-oriented scientific strategy; **(ii) to consolidate international leadership** by capitalizing on a vibrant national research community from various research institutes and universities. To this end, we have intentionally set priorities in the areas in which we can have the greatest impact. FORESTT will also **encourage strategic collaborations with international partners in the pursuit of common goals**; **(iii) to promote dialog between science and society, and the co-production** of pertinent forest management strategies and decision support tools, and to **foster a culture of public-private partnerships** in support of shared interests; and **(iv) to leverage the wealth of research infrastructures**. This approach should open up new research avenues for attaining the anticipatory and predictive goals of wood and forest research of the PEPR initiative.

To answer the scientific challenges linked to SFM in the context of global change, FORESTT identified the four main scientific challenges detailed in the next section.

1.4. SCIENTIFIC AND TECHNICAL OBSTACLES LIKELY TO BE REMOVED

The FORESTT program is organized into four **scientific challenges** (SC#1-SC#4 describe hereafter) tackling urgent challenges facing the forests of France and the rest of the world. By operating through two main funding instruments: (i) focal projects (see section 2.2.1) and open calls for collaborative projects (see section 2.2.2), these challenges will **generate data and knowledge** to overcome scientific and technical barriers, making it possible to **disseminate results** to stakeholders, end-users, and the general public, **pool energies and resources,** and **provide decision support tools, recommendations and guidelines** to promote transformative actions by forest stakeholders, through the renewal of forest governance, improvements in forest resilience, enhanced biodiversity and forest ecosystem services. FORESTT will **(i) advance knowledge** on a limited number of hot research topics, crossing disciplinary boundaries when necessary to tackle complex scientific questions, but also favoring a transition from consultative to co-constructive research practices, by promoting the engagement of stakeholders in research (and in the interconnected parts of the research process: hypothesis formulation, experimental design, data generation, data analysis, and the presentation of findings) and involving societal actors in the innovation process, **(ii) develop and use *in situ, in lab* and *in silico* infrastructures** and to integrate them into international networks, **(iii) stimulate networking** (not only among scientists, but also between researchers and stakeholders) at the national and international levels, **(iv) improve data and information management and data processing practices,** with the support of digital transformation and the integration of open science and FAIR policy requirements,

and **(v) promote and strengthen capacity-building in higher education** and **continuous training**, to understand and deal with the complexity in social and ecological forest transitions.



An overview of the main **scientific knowledge gaps** to be filled by new lines of research, the current **technical obstacles** to be overcome and the **research priorities** enabling us to reach our ambition of a successful transition of FSES, is provided below for each of the four cutting-edge scientific challenges identified by the FORESTT scientific community. These gaps have also been identified as important by the forest stakeholder community and policy-makers on the ground (as attested by the recent "Forest and Wood Dialog"). By addressing these issues and co-constructing solutions, we will facilitate and catalyze the implementation of effective responses at local, regional, national and international levels. Finally, FORESTT will lead to **immediate outcomes** with benefits or changes (**expected impacts**) over a longer timeframe.

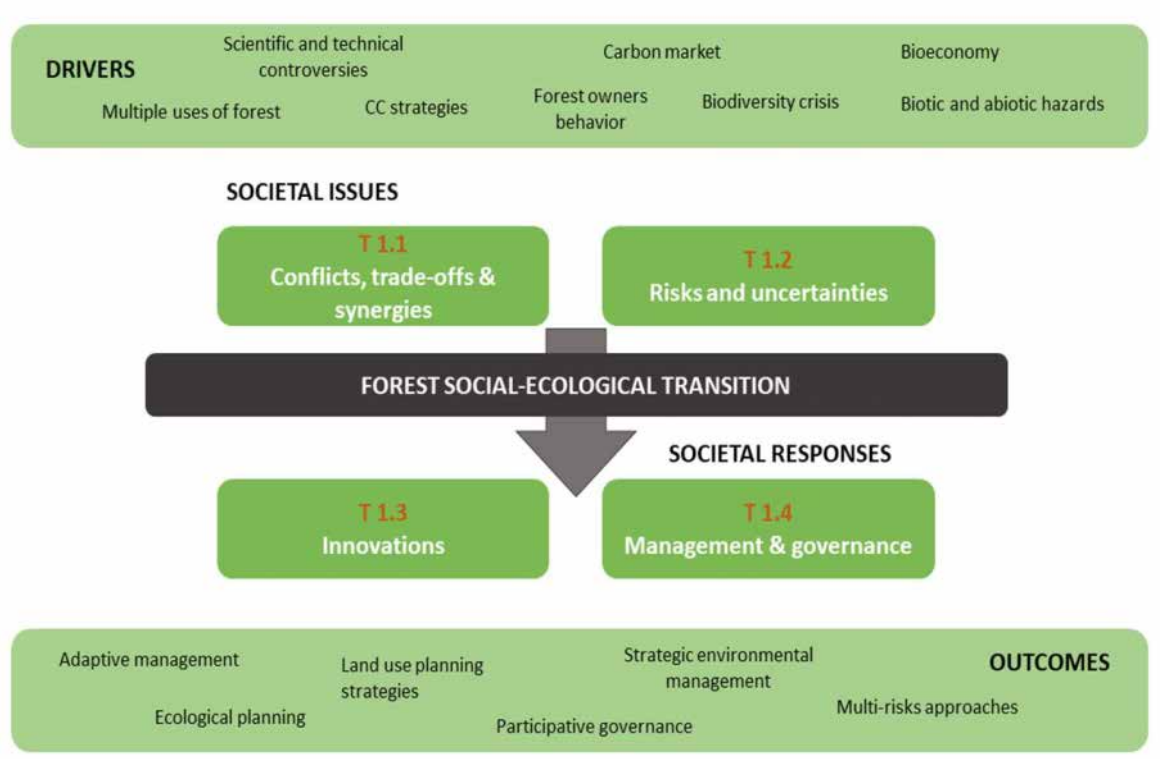
2. FOUR SCIENTIFIC CHALLENGES

2. 1. SCIENTIFIC CHALLENGE #1: ADDRESSING THE SOCIETAL CHALLENGES OF FOREST SOCIAL-ECOLOGICAL TRANSITION

Context and challenges: Forest management and practices are systematically determined by the behavior of various actors within a diversity of institutional arrangements. Forests are at the center of societal debates on ecological transition, from local to global scales. Forest-society relationships are complex and have long been associated with diverse policies, stakeholders and activities influencing

or influenced by forests[20]. Significant scientific investment is, therefore, required to understand the combined functioning of societies and ecosystems. Social sciences and economics research seeks to provide more evidence-based information on the societal factors influencing ecosystem dynamics and management. A shift in scientific thinking is required, to place forest-society relationships at the core of the agenda of general research on the challenges posed by the global ecological transition. Finally, multiscale analyses are required, and research analyzing and comparing the management and governance of locally situated configurations from a global perspective should be encouraged.

Priorities: This challenge will address the interactions between human activities and forest ecosystems involved in the social-ecological transition. It will revolve around four research priorities. Target 1.1 (T1.1) and T1.2 will concentrate on societal issues associated with the forest social-ecological transition ("Conflicts" and "Risks"), whereas T1.3 and T1.4 will explore existing and emerging societal responses to the transformation of forest management strategies and practices ("Innovation" and "Governance & Management").



Priority 1.1. Analyses of trade-offs, conflicts and synergies associated with the forest social-ecological transition

A social-ecological transition may alter existing trade-offs and synergies or generate new trade-offs between forest ecosystem services (*e.g.,* carbon sequestration *vs.* wood mobilization). In the short and long term, these trade-offs can result in conflicts between actors, generally creating winners and losers[21]. In addition, forest conservation/restoration often generates conflicts with other sectors (*e.g.,* agriculture) or land-use strategies (*e.g.,* urbanization). Ecosystem service valuation has risen to prominence as a method for addressing these trade-offs and synergies. However, there has been criticism or approaches applying exclusively conventional cost–benefit analyses to biodiversity and ecosystem services. Alternative approaches would involve the use of multiple approaches to justify the promotion of forest ecosystem services. If forests and their associated ecosystem services are quantified only in terms of economic value, with focus on the supply side of the forest ecosystem, important social, cultural and political dimensions might be missed that could reveal, for example, the unequal and asymmetric power of negotiation between actors and the diversity of modes of governance[22]. **Target 1.1.1**: Categorizing and mapping forest management trade-offs and synergies at different spatial and temporal scales. Inventorying and documenting forest conflicts resulting in social mobilization or political disputes. **Target 1.1.2**: Given that the assessment of ecosystem services involves multiple domains (*e.g.,* biophysical, socio-cultural, and economic), we intend to conduct research acknowledging the fact that ecosystem services are mediated by complex social, cultural and economic filters that differ between local contexts (between tropical and temperate regions in particular). **Target 1.1.3**: Developing conceptual approaches for multiple ecosystem services management and using decision support systems to provide information about trade-offs and synergies between management strategies and planning criteria at different scales, and to explore land sharing/land sparing strategies[23]. These decision support tools also require means of comparing alternative management strategies under conditions of uncertainty, and this requires a method for

comparing monetary and non-monetary values, services and metrics for non-quantitative services. We will, in particular, address land-use planning strategies through analyses of the spatial arrangement of forest cover and changes in that cover (link with SC#4), particularly in tropical contexts, including deforestation and forest fragmentation[24].

Priority 1.2. Developing tools and promoting behaviors favoring better resilience to risk exposure

Risks and uncertainty have always been an important component of forest management decisions and activities. Research has contributed to the characterization of risks, particularly for fires, windstorms and pests. The attitudes of foresters towards risk have also been a subject of interest for several years now. Theoretical studies have considered the impact of the risk aversion of foresters on various types of decision[25]. The challenge ahead is to include uncertainty as a structural component of forest management and to adopt a multirisk approach. This multirisk approach should consider environmental hazards (SC#3), but also risks and uncertainties associated with changes in political context, social expectations and economic orientations (SC#2). Many natural hazards, corresponding to extreme climatic events or slow-onset phenomena, disrupt social cohesion and reduce the capacity of people to adapt, making forest ecosystems less resilient to environmental stresses[26]. It is, therefore, necessary to adopt a dynamic social approach to vulnerability and unequal capacities, to understand why some communities and individuals are disproportionately exposed to and affected by risks, including climatic threats in particular[27]. **Target 1.2.1**: Developing a multirisk approach to climate change impacts and other stressors in forest economic models and in forest management and planning systems. Together with SC#3, this target will address the selection and aggregation of suitable hazard and vulnerability metrics for combining information about multiple climate impacts, spatial analyses and the ranking of risks, including their communication to end-users[28]. **Target 1.2.2**: Analyzing the conditions for the emergence and spread of a culture of risk management among the

various public and private actors. **Target 1.2.3**: Developing tools (*e.g.,* organizational, economic and financial) for risk anticipation, increasing social and economic capacities to recover from disasters, and developing crisis prevention and management strategies.

Priority 1.3. Fostering innovation and science-based expertise to support social-ecological transition

The French forest sector is traditionally regarded as a low-tech, low-innovation sector with conservative practices[29]. However, the need to increase the economic and environmental performance of the forest-based sector is fostering innovation and promoting new digital support for forest management, new organizational tools and new silvicultural practices, for example. Furthermore, as scientists are increasingly asked to provide relevant adaptive forest management tools and strategies, they are experiencing new science-action relationships through close collaborations with experts and stakeholders, and through new information-sharing practices[30]. Socio-technical transition theory and science and technology studies have become influential approaches for understanding the co-evolution of societies, science and innovations. However, they have focused mostly on technology-driven innovations, and have largely ignored the forest sector. **Target 1.3.1**: Studying the role of science and expertise in the forest sector (especially in the field of ecology – SC#3), to evaluate their contributions to altering management practices (especially for mitigation and adaptation strategies), and analyzing the factors facilitating or hampering their diffusion among forest owners and foresters. **Target 1.3.2**: Understanding the emergence of innovations (social, technical, organizational, and institutional) in the forest sector: who promotes innovations, who are their detractors, and how do these innovations challenge existing management strategies and practices? **Target 1.3.3**: Analyzing the territorial dimensions and dynamics of socio-technical change, to characterize the diversity of transition pathways in forest management and to improve the production and dissemination of knowledge to decision-makers, forest stakeholders and civil society.

Priority 1.4. Exploring and assessing the diversity of forest management practices and modes of governance

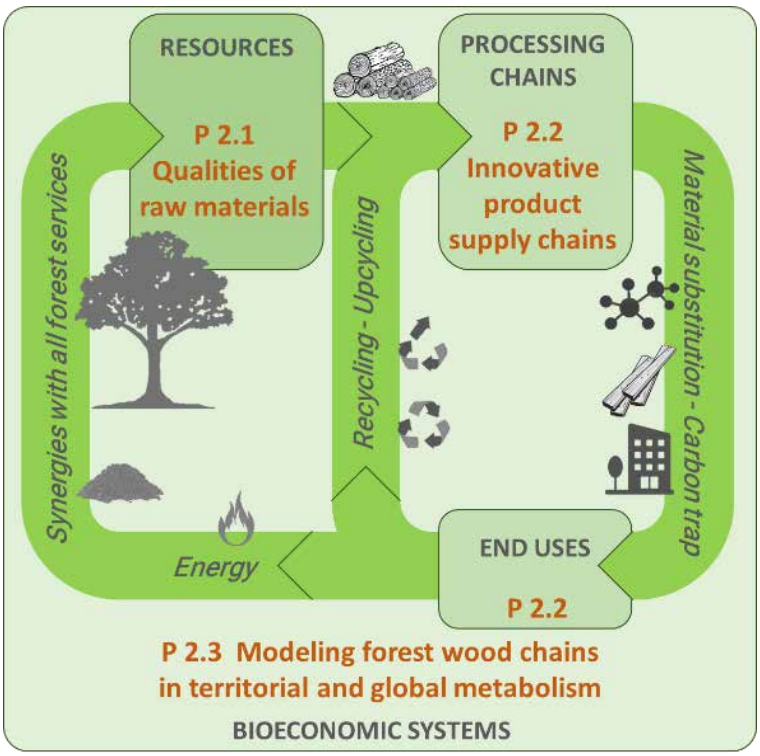
Traditional approaches to forest governance (generally by the State) have been criticized as rather inefficient, and new forms of governance are emerging[31]. Forest governance is also an important geopolitical issue relating to global economies and environmental problems. Multilevel coordination, decentralization, public participation, inter-sectoral approaches, and more incentive-based forms of regulation are being promoted. Forest management has long been set in a framework in which it is guided by regulatory and fiscal instruments, but we now need to consider the development of private initiatives, such as certification and market-based instruments (*e.g.*, carbon market). The challenge is understanding the effect of these instruments on the implementation of new forest management strategies and their effective contribution to environmental performance (in conjunction with SC#3). The main deliverable of FORESTT for this priority will be an ambitious comparative and critical approach to forest politics, policy, and management strategies. **Target 1.4.1**: Mapping and evaluating the coherence of the multilevel and multisectoral political context of FSES management (from local to international levels). **Target 1.4.2**: Characterizing the different strategies of stakeholder groups (including environmental NGOs, industrialists, citizens' movements) concerned by forest issues. Research needs to acquire more information on forest stakeholders to capture the diversity of representations, discourses and interests involved in the transition process. The challenge is closely studying the democratic mechanisms of decision-making in the forest sector. **Target 1.4.3**: Anticipating changes in forest management systems and governance practices. We expect here to provide documented worldwide experiences of governance and management practices contributing to an effective social-ecological transition and a better orchestration of forest-related policies.

2.2. SCIENTIFIC CHALLENGE #2: DEVELOPING A CIRCULAR AND AGILE WOOD-BASED BIOECONOMY

Context and challenges: Forest bioeconomy[32] is expected to play a key role in smart and green growth, with consolidation of the traditional wood-based sector but also, given their potential for development, new bioeconomy products, such as advanced biofuels, intelligent packaging, innovative wooden buildings, biotextiles, and biochemicals. Wood products are of significant value globally, providing materials, energy and molecules, and non-timber or non-industrial forest products that may be important locally and must be considered complementary in territorial systems in both temperate and tropical regions. The full forest sector in France plays an important economic and social role, with 393,000 jobs, 12.5% in the manufacturing industry, and a turnover of 60 billion Euros annually[33]. Wood is a complex, multipurpose natural material[34], with performances that only high-tech synthetic products can mimic. Through the myriad uses of wood, the role of forests in climate change mitigation is not limited to carbon sequestration in forest ecosystems but also extends to storage in wood products and the use of wood to replace products associated with greater greenhouse gas emissions[35]. However, choosing between more intensive harvesting to support a bioeconomy *vs.* keeping older forests for carbon storage in ecosystems is a complex issue [36,37]. The development of a wood-based bioeconomy therefore requires new scientific knowledge, to improve both circularity (*i.e.,* cascading uses and recycling/upcycling) and flexibility (*i.e.,* the capacity of bioeconomy actors to adapt to changing and uncertain resources and markets[38]). Wood science has developed in France since the 1980s and led to the development of a research community that has, since 2012, been structured into a national wood science group, "GDR in Wood Sciences" (450 permanent researchers), including R&D and industrial partners but with strong support from basic sciences. This network rapidly and efficiently incorporates new players in the complexity and interdisciplinarity of wood sciences, organizing training, mobility, international networking (*i.e.*, the European INNOVAWOOD organization), or the sharing of facilities. This network combines diverse skills, from the "usual" wood sciences and

engineering, to the skills of biologists, foresters and social scientists on wood. In FORESTT, the challenge is to get this community and new actors to engage in a common research program with a systemic view and the aim of developing a more agile wood-based bioeconomy.

Priorities: The wood industry has always been driven by processes and markets, resulting in increasingly standardized production. The modern wood industry is less able than traditional craftsmen to make use of diverse species and is therefore more dependent on simple planted forests with very few species. In a global market with more specialized territories, only a few processed wood products have a high added value, and these products can be transported around the world. Any future efficient wood-based bioeconomy would need to be driven by resource capacities, valorizing the heterogeneous and changing raw materials provided by changing, resilient and biodiverse forest ecosystems. Moreover, as wood can be produced everywhere, the impacts on sustainability of using local resources or of specializing territories should be assessed. Challenge #2 will address these issues by focusing on the following three priorities: (i) the multidimensional aspects of wood qualities (P2.1), (ii) exploring wood processing opportunities to optimize the valorization of all the qualities of a resource, including recycling and upcycling (P2.2), and (iii) multicriteria analysis of the coupling of bioeconomic systems and the enlargement of life cycle analysis and economic models (P2.3).



Priority 2.1. Promoting 'Qualities' of raw materials

If we are to improve the use of a heterogeneous and variable resource, the first scientific issue to be addressed is the qualification of the resource, through sorting, grading, and modeling of its dynamic changes. **Target 2.1.1** is divided into three components: (i) Defining sets of wood properties that make wood more suitable for a range of uses, (ii) developing methods for assessing these properties in laboratory, forests, and industrial conditions, (iii) designing databases of wood variability. Relevant properties include structural, chemical (*e.g.,*[39]), physical, optical (color) and more integrated technological properties (such as machining, drying or glueing ability) and their interdependencies. Wood durability is a very important property for outdoor use[40]. The diversity of uses of wood will be considered, but priority will be given to addressing the growing demand for timber for building (the structural properties of timber are important, not just the properties of the wood) and packaging. However, bioeconomy value-chains are, necessarily, based on diverse uses, and high-added value uses (*e.g.,* green chemistry, barrels) and energy must be factored in. **Target 2.1.2:** Wood biomass composition and wood properties vary considerably, but not randomly, and they must be predicted and oriented in future resources exposed to climate change and new forest management practices. This target will involve research into the determinants (ontogenetic, genetic and environmental) of these traits (*e.g.,*[41,42]) with the mobilization of basic research on wood formation processes and mean wood density with cellular/composite material sciences (*e.g.,*[43]) to provide information about the entire set of studied properties. There will be a particular focus on the exploration of interactions between determinants, and the specific impacts of increasing variation in annual climate conditions and extreme events on wood properties. **Target 2.1.3:** Assessing potential uses (hardness *vs.* softness quality criteria). Wood quality is defined not only by the concrete criteria of target 2.1.1, but also by human practices and skills, in the real world of uses[44]. This target will therefore require cross-disciplinary approaches, including analyses of the results of target 2.1.1 from the standpoints of wood engineering and socio-economic systems. The deliverables will be methods for anticipating wood uses

and paradoxical (but common) situations in which an abundant resource is used efficiently despite its "low" quality or, conversely, is not used despite its "high" quality.

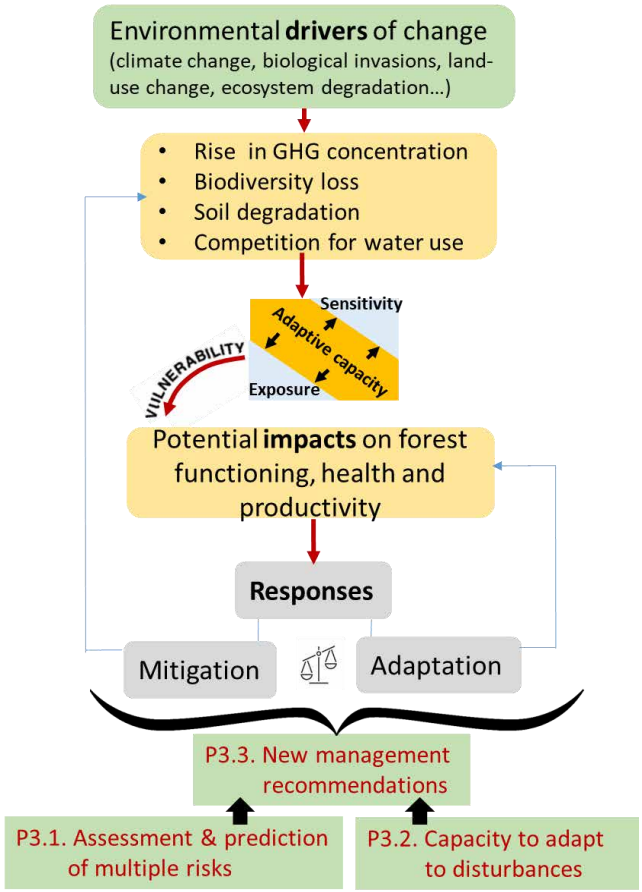
Priority 2.2. Fostering responsible and sustainable innovative products and processes

FORESTT will orient R&D fostered by innovation in materials, energy, and molecular process engineering to develop a bioeconomic view centered on resource valorization. It will take into account (i) the diversity of raw materials (such as decayed wood from forest health crises, secondary species, hardwood species and new species of interest), (ii) the development of innovative products and supply chains, and new treatments and processes for generating green products or avoiding the use of adjuvants, (iii) deconstruction and recycling at the end of the product life, to improve the circularity of the bioeconomy and its carbon balance[45]. The sustainability (including social responsibility) criteria of process and product design will be studied with a view to preparing priority 2.3. **Target 2.2.1:** Valuing the diversity and performance of wood structures (lightweight, fiber-reinforced cell walls) in new materials and systems for building and packaging, based on local resources and hardwoods[48]. **Target 2.2.2:** Adapting the ongoing development of deconstruction processes to the diversity of forest resources and market demands. Chemical deconstruction can generate platform molecules that can replace petrochemical compounds[46], whereas thermal deconstruction produces a new pretreated biomass through partial deconstruction of the main biopolymers. **Target 2.2.3:** Recycling at the end of product life: new design, biological processes, chemical treatments or thermochemical pathways for the decontamination and production of fresh biomass, molecules, biochar, or energy[47]. **Target 2.2.4:** Analyzing products and processes to derive relevant data for further assessments of the impact on sustainability of the bioeconomy system (see priority 2.3). In addition to life cycle analysis, emphasis will be placed on other indicators, including those relating to health and comfort, or employment.

Priority 2.3. Assessment of the sustainability of bioeconomic systems, including territorial and global metabolism

This priority focuses on bioeconomy as a territorial and global system. Environmental sustainability principles are increasingly being integrated into comprehensive definitions of a circular bioeconomy, but many studies have concluded that the contribution of bioeconomy to sustainability is not necessarily positive[49]. In addition, the opportunities afforded by markets for bioproducts must allow a revival of forest economy and, in particular, an increase in the added value of the wood sector, which would be beneficial to both the national economy and local development. However, the underlying economic, social, and political mechanisms have been little studied[50]. **Target 2.3.1**: Developing an inclusive model of the forest bioeconomy, along with suitable metrics for monitoring the progress of regional, national, and international policies in line with broader economic and sustainability issues. We need to identify the main trends and developing uses of wood, including how that will affect forest management and other uses of forests. We also need a combination of economic, environmental, and social information about forest product value chains, from the forest management to final product consumption stages. Environmental and global economic models of the forest sector will be used[51-53]. **Target 2.3.2**: Developing environmental assessments based on quantitative assessments of material flows[54], *i.e.,* within the whole forest-wood system, from forest growth to end uses. In addition to current life cycle analysis and the current model on material flow analysis of supply chains[55], these assessments must include a dynamic view, based on mechanistic analyses of resource growth, qualities and of wood processes/products (from priorities 2.1 and 2.2)[56–58]. **Target 2.3.3**: Analyzing the "bioeconomy being developed", as a means of studying the implementation of industrial projects in detail and assessing the conditions for their territorial integration. We will focus on this integration in territories with several overlapping issues: areas of residence and consumption, such as cities and peri-urban areas, and territories with alternative land uses, such as areas strongly invested in agriculture.

2.3. SCIENTIFIC CHALLENGE #3: FOSTERING ADAPTATION, RESILIENCE AND MITIGATION CAPACITIES OF FOREST ECOSYSTEMS



Context and challenges: Adaptation and mitigation are interlaced complementary strategies for limiting the effects of global change on forest ecosystems. They have mostly been addressed separately in previous research efforts, but FORESTT will adopt a coupled approach, to address synergies and trade-offs, together with the different spatial and temporal scales at which these processes operate. In addition to research on mitigating the increase in CO_2 levels, FORESTT will distinguish itself by considering the capacity of forests to mitigate other major ecological perturbations, including biodiversity wildlife habitat loss, emerging pests and pathogens, and soil degradation. Global change represents a significant risk to forests and a major challenge for forest managers. Mitigating these risks requires the management of genetic, structural and functional diversity and the adoption of innovative and agile forest management practices (adaptive management) to increase the resistance and recovery of natural and planted forests in the face of biotic and abiotic disturbances. These practical approaches will be supported by advanced science-based knowledge concerning the characterization of risks, their interactions and their impact on forest functioning, vitality and recovery after disturbances.

Priorities: This challenge will be met through three complementary priorities aiming: (i) to improve our understanding of the mechanisms underlying forest responses to disturbances and crises, for the prediction of forest resilience (P3.1), (ii) to acquire in-depth knowledge of the physiological, evolutionary and ecological processes enabling individuals, populations, species and communities to adapt to multiple stresses (P3.2), and (iii) to propose efficient adaptive forest management practices to reduce risks, maintain vitality and support the contribution of forests to human well-being (P3.3).

Priority 3.1. Improve understanding and prediction of forest resilience to global change

Forests are increasingly exposed to multiple abiotic and biotic hazards over a wide range of spatio-temporal scales, which jeopardize their integrity and capacity to deliver ecosystem services. It remains difficult to assess their overall impact on forest vitality, productivity, and functioning, particularly due to cascades or interactions between these hazards, influencing the magnitude of their consequences[59]. It is therefore of utmost importance to better characterize the capacity of forest ecosystems to resist these disturbances and then to recover their structure and functioning, i.e. the two dimensions of their resilience. In addition to improving the assessment of forest ecosystem resistance to these multiple hazards, it will be important to evaluate their recovery capacity to such complex disturbances, and to identify possible tipping points[60,61]. **Target 3.1.1**: Forest productivity is declining globally (-3% in the last ten years in France, NFI 2022) and forest mortality is increasing. FORESTT will therefore place priority on **evaluating and understanding the determinants of losses of forest ecosystem productivity and tree mortality** following disturbances associated with cascades and extreme events. An entire Focal Project (FP#2 in section 2.2.1) will be dedicated to multi-risk analysis and management, with a specific task on vulnerabilities. It will be fed by experiments focusing on the identification and measurement of key functional traits involved in tree resistance (*e.g.,*[62,63]). The new insight obtained will help to improve current forest demographic and growth models for predicting productivity losses, mortality risks and shifts in the distributions of tree species, in connection with

monitoring of the forest state (SC#4). Efforts to reduce the uncertainty in these models will be crucial in order to improve their application in decision support. **Target 3.1.2**: A second important pillar of sustainable forests, which remains poorly understood, is their **spontaneous ability to recover after disturbances**[64,65]. A better understanding of the natural regeneration processes of forests and the speed of restoration is key in this context. The development of observation methods for monitoring the roles of tree fecundity and natural regeneration in the forest response to climate change[66,67] and biotic disturbances are also major scientific and technical issues that will need to be addressed. Long-term surveys and retrospective studies and simulations (with the models developed in Target 3.1.1) will be used to characterize tipping points, to quantify the resilience of forest functions after catastrophic events, and to identify post-disaster management interventions more successful than the natural regeneration without management.

Priority 3.2. Ecological and evolutionary adaptation processes to maintain forest ecosystem functioning and services under conditions of global change

The ability of long-lived forest trees to adapt to non-steady-state environmental conditions and to recover or regenerate after disturbances is a crucial research question[65,68,69] that is also of considerable interest to forest managers. The relatively slow growth of trees and the inertia of forest dynamics, coupled with the acceleration of global change pressures, calls for improvements in our understanding of the relationship between physiological, ecological, and evolutionary changes, which can occur over similar timescales[70]. **Target 3.2.1**: **Within-species genetic diversity is the ultimate source of biological diversity**. The monitoring of this major driver of forest resilience is crucial to ensure the vitality and adaptability of forests to environmental change. FORESTT will promote the development of DNA-based methods, pangenome construction and their application to (i) the discovery of genetic and epigenetic variation of importance for adaptation, thus improving the prediction of current and future adaptive-trait variation across species ranges, and providing key

information for the selection of populations for afforestation and reforestation programs. Adaptive introgression through inter-specific gene flow, a widespread but still untapped evolutionary mechanism of tree adaptation, will be also explored, (ii) the identification of endangered genetic resources at risk of extinction and the design of conservation strategies to halt genetic erosion, (iii) the fostering of forest management practices taking ecological and evolutionary processes into account[71], and enhancing the natural heritage value of a wide range of forest species of current and future interest, for the design of improved varieties for planted forests adapted to future environmental conditions. **Target 3.2.2**: FORESTT will **consider the relationships of molecular diversity to the diversity of functional traits**, which underlie adaptation and survival. The program will favor the achievement of significant breakthroughs and the development of predictive models, by developing and applying methods for obtaining high-throughput, low-cost phenotypes and environmental descriptors *in natura*, to characterize genotype-environment-phenotype-fitness functions, and to couple such studies with research in controlled environments. The program will foster the use of technology (*e.g.,* remote sensing in conjunction with SC#4, metabolomics, dendro-phenotypes, etc.) for the rapid and precise characterization of trees and their environment, and analytical methods (*e.g.,* machine and deep learning) to unravel the potentially complex links between genotypes, epigenotypes, environment, phenotype, and fitness. **Target 3.2.3**: Trees are not isolated individuals in an abiotic environment. Instead, they live and grow in a **network of interactions** with microorganisms[72] and invertebrates. It will, therefore, be necessary to improve descriptions of this complexity, to understand the dynamics of these interactions, and to analyze how these interactions participate in the above- and below-ground processes of adaptation of the whole forest ecosystem to environmental constraints, while contributing to the provision of ecosystem services. Metabarcoding and environmental DNA analyses and disciplines such as entomology, epidemiology, pathology, microbiology, functional and community ecology will need to be combined to allow these advances in knowledge and to improve adaptation strategies.

Priority 3.3. Designing new management alternatives to improve the adaptation, mitigation and provisioning capacities of forest stands and landscapes

Having improved the assessment and prediction of multiple risks driven by global change, and our understanding of the capacities of individuals, populations, species and communities to adapt to these unprecedented disturbances, we will then need to translate this knowledge into recommendations for managers. **Target 3.3.1**: A consensus is emerging in the scientific community that the functional diversity of forests can favor their resistance[73] and multifunctionality[74]. The new European strategy for forests recommends the maintenance or planting of mixed-species forests. However, mixed forests can be less productive than fast-growing monospecific stands, are more complex to manage and their products are not particularly well-suited to the wood market (see SC#2). At the stand scale, field experiments and computer simulations will ,therefore, be required, to **design, evaluate and support the transition from monocultures to economically viable mixed (or uneven-aged) forests**[75] and to provide management guidelines[76]. New management strategies are also required for afforestation (targeting enrichment in genetic material better adapted to the risks identified) and natural regeneration, and/or their combination (*e.g.*, species enrichment). This research will rely on interdisciplinary approaches (link with SC#1) considering the whole set of ecosystem functions and services, their trade-offs, the evaluation of practical caveats, and cost-benefit analyses[77]. The lessons learnt from resilience studies will provide support for continuous adaptive management strategies. **Target 3.3.2**: Advances in landscape ecology and spatially explicit computations have shown that a combination of land-sharing and land-sparing approaches (*e.g.*[78]) could optimize the provision of forest ecosystem services and products at the landscape level. It is, therefore, necessary to develop research aiming to understand **how the spatial distribution of different forest stand types and management systems contributes to adaptation and risk mitigation and to the provision of goods and services,** including biodiversity conservation. This work will mobilize diverse disciplines, including

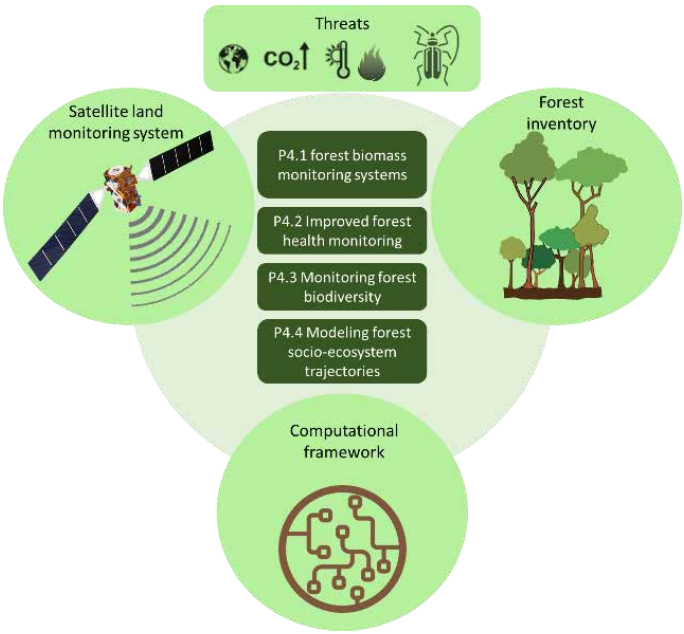
spatial ecology, risk sciences, management sciences, biogeochemical cycle analysis and modeling, supported by a network of landscape-scale experiments and associated living labs.

2.4. SCIENTIFIC CHALLENGE #4: FOREST MONITORING FOR SCIENCE, MANAGEMENT AND POLICY

Context and challenges: French forests provide a unique opportunity for research and innovation in forest monitoring, as they encompass 17 M ha of temperate forest and 8 M ha of tropical forest (French Guiana). Current knowledge on forests is based on long-term observational systems. FORESTT will contribute to increasing the capacity of forest monitoring by using recent advances in scientific research. These systems will provide information on the challenges of forest multifunctionality and ecosystem services, and global change biology. Ultimately, they should also aim to provide evidence for the adaptation of forests. FORESTT will monitor an extended set of attributes, such as forest cover, carbon storage, biomass resource availability, biodiversity, forest vitality and vulnerability. The challenge of forest monitoring is increasingly becoming global, due to international agreements (*e.g.,* the global stock-take of the Paris Agreement[2]). It has also increased in importance in continental Europe, where both forest areas and stocks are increasing, in a context of intensive forest management, and where the balance between bioeconomy-oriented wood valorization and forest protection is explicit. The European Commission[1] has recently pointed out that information about forests is patchy and that a consistent and comprehensive monitoring framework is lacking across European countries. This problem is even more acute in the tropics[79]. FORESTT will seek to provide knowledge at EU and global scale. Monitoring and data integration activities generate employment in the private sector and foster new alliances between public and private stakeholders.

Priorities: Priority 4.1 will leverage major recent technological advances, fostering progress for all three essential pillars of a forest biomass monitoring system: remote sensing, forest inventory design, observation/experimental field networks and computational frameworks. Priority 4.2 will ensure that

monitoring systems also provide early-warning signals for threats (vulnerability to pest attacks, air pollution, fire, drought, frost and storms[80]) and spontaneous dynamics. Priority 4.3 will explore the implementation of innovative approaches and technologies for monitoring forest biodiversity. Priority 4.4 will address the streamlining of these monitoring systems into integrative modeling frameworks to support forest governance and policy development for both conservation and production.



Priority 4.1. Promoting the development of higher-resolution forest biomass-monitoring systems

Current biomass forest monitoring systems are designed to provide information about forest status and trends. However, they display little harmonization, and this constitutes an obstacle to sound strategic planning and a comprehensive understanding of the various functions of forests (SC#1). Remote sensing is also promising but is subject to limitations on its use for forest monitoring and reporting. We plan to lift these current limitations, by addressing four interrelated targets. **Target 4.1.1: Forest biomass** is a crucial metric for natural climate solutions in the LULUCF sector. We will conduct ground-based observations combining long-established inventory approaches and remote sensing[81]. These new advances will contribute to interplay between forest economics, governance and stakeholders at the local-to-regional scales. French Guiana will serve as a case study, with the development of dedicated monitoring capacity for this territory, which will be used to inspire other tropical countries to improve their forest monitoring systems. **Target 4.1.2:** Detecting forest

degradation **in near-real time** is a key asset for the bioeconomy (SC#2), land-use management and carbon emission-offsetting strategies. Temporal resolution will be increased by remote sensing through the Copernicus EU program. In France, the partner CNES Space Climate Observatory is processing these time series. The integration of remote sensing and forest inventories is a key objective here. **Target 4.1.3: Very high-spatial resolution** data are becoming easily accessible. France has complete coverage at a resolution of less than 1 m, by optical (20 cm), 3D-photogrammetry, and Lidar (A-Lidar) imaging. These vast volumes of data require efficient computational frameworks, based on deep learning[82]. Public-sector partners and private-sector companies will be coordinated to generate agile processing chains with the potential to map forest cover, hedges and isolated trees in France, which is of importance for public policy-making and management. **Target 4.1.4:** The launch of two global forest biomass observation missions is planned within the next two years. However, the quality of these missions will depend on **ground calibration/validation**. France, with its diverse forests (from temperate, Mediterranean and alpine to equatorial), is well-placed to contribute through the GEO-TREES initiative, coordinating data acquisition for tree inventories at 100 sites globally, with at least 10 ha of forest inventoried tree-by-tree, and 1,000 ha of forest covered by drone or airborne Lidar. This input will be crucial for innovative biomass-related satellite missions.

Priority 4.2. Towards improved forest health monitoring

One of the major focus in forest monitoring has been the assessment of forest dieback risk (see SC#3). Existing ground-based monitoring programs characterize the responses of crown condition to climate, and natural and human-induced environmental changes. Design continuity is an asset, but greater valorization would be possible if existing national and supranational investments were harmonized. **Target 4.2.1:** Forest health decline should be evaluated as a function of changes in mortality, canopy cover, or optical properties. Forest risk survey systems are already operational[83], and tree defoliation is a useful early-warning signal of a deterioration of tree status[84]. FORESTT will make use of this

existing infrastructure and will build on attempts to **determine the causes of defoliation**. Annual health assessments will be performed, to explore the links between forest health and vitality and their biotic/abiotic determinants. **Target 4.2.2:** We will build on advances in **biophysical modeling and airborne spectroscopy** to generate metrics of canopy health (*e.g.*,[85]). Such information, combined with high-resolution ground datasets and time series, would produce extremely powerful alert systems for the early detection of pest attacks, and annual indicators of forest health. **Target 4.2.3:** The ultimate stage of forest degradation is **tree mortality**. It is difficult to monitor mortality effectively[86], but individual crown detection methods could be transformative. Airborne Lidar systems with frequent revisit times (in temperate and tropical forests) will constitute the next technological advance.

Priority 4.3. Monitoring forest tree biodiversity

Globally, forests are seen as privileged shelters of biodiversity, and the preservation of both old-growth and secondary forests can help to curb biodiversity erosion. This is a pressing concern in the tropics[87], but is also mentioned in the 2030 EU Forest Strategy[1]. For instance, French temperate forests are crucial for conservation[87,88]. Forest communities are composed of many taxonomic groups, but this priority will initially focus on woody plants, the structural element of forests. **Target 4.3.1:** Describing plant biodiversity in forests, particularly in the tropics, is a major challenge underpinning timber trade policy and forest adaptation strategies. **Agile methods of taxonomic determination** are being developed[89] and involve (i) photographs and convolutional deep learning, (ii) leaf and wood near-infrared spectrometry for tropical species complexes, (iii) high-throughput DNA sequencing on plant tissues (SC#3). FORESTT will seek to improve our understanding of tree diversity worldwide, contributing to the establishment of knowledge concerning the biodiversity of the world's forests and the development of actionable decision tools to support biodiversity conservation. **Target 4.3.2: Hyperspectral imaging** can be used to establish tools for the monitoring of forest diversity[90]. It can retrieve data for key attributes, such as the contents of nitrogen, cellulose, and phenolic compounds,

or leaf mass per unit area[91]. FORESTT will support the scientific community in preparing for the arrival of global hyperspectral data from the upcoming CHIME satellite in 2029. **Target 4.3.3:** FORESTT will advance the **monitoring of taxonomic and functional forest diversity** across tropical and temperate forests. France is in a unique position to contribute to the global description and monitoring of forest biodiversity, through a major investment in overseas territories and in the tropics. In temperate-zone monitoring networks, MNHN provides support for inventories of forest biodiversity, and IGN conducts systematic biodiversity inventories.

Priority 4.4. Modeling forest trajectories to support forest governance and management

Forest modeling is a crucial tool for analysis, forecasting, and data integration. Modeling is essential to strengthen interdisciplinarity and to provide robust science-based methods to support decision-making and management. Models also enforce data standardization, ensuring that data are interoperable and reusable. A large research community is already involved in forest modeling[92], and FORESTT will support model development, comparisons between models and data integration[93]. **Target 4.4.1:** FORESTT will support advances in forest modeling approaches, building on the **biophysical basis of forest ecosystems**. As components of broader Earth system models, these approaches will build realistic representations of forests to address management scenarios (SC#1), and the impact of environmental threats (SC#3). The French ORCHIDEE Surface Model[94] implements integrated representations of forest ecosystems[95]. Large-scale forest models are useful for exploring the link between forest management and climate forcing for the determination of baseline for forest adaptation[96]. They can also be combined with policy analyses[97] and coupled with process-based models. **Target 4.4.2:** FORESTT will harness the potential of **process-based models** to support analyses of the effects of risks on forest ecosystems (SC#3). Such models account for the diversity of species, the complexity of their interactions, and the re-assembly of forest species following modifications to climate, or under alien or invasive pest and disease pressures. Increasing detail from evidence-based

models and improvements in computational efficiency are opening up new avenues of research at the landscape[98] to regional [99] scales. Such forest models will be vital, to address the effect of changes in forest management and regime disturbances on the spread of risks, and to simulate the trajectories of responses to disturbances, to identify the most resilient systems.

3. PROGRAM IMPLEMENTATION: DETAILED PLAN

3.1. COORDINATION STRATEGY

The role of FORESTT extends beyond the scientific management of focal projects or open calls for collaborative projects. Its leadership actions will include the following:

(i) **Capacity-building in the scientific community**, making use of existing regional, national, and international networks, energizing collaboration and interdisciplinary research to design transformative pathways. The scientific community assembled to construct the focal projects encompasses a broad range of disciplines and expertise. The institutions participating in FORESTT house world-renowned science facilities that are highly attractive to top-level researchers and these projects already include recognized leaders of their fields. Much of the research is performed in collaboration with scientists and organizations from around the world, creating an extensive network of collaborators that will be reinforced by the mobility actions of the program. These are some of the main assets of FORESTT for addressing complex and global challenges. Beyond the focal projects, additional major changes will be required to achieve the expected impact of the PEPR program: (1) encouragement of interdisciplinarity in the open call guided by the overarching FSES vision and clear intended impact rather than narrowly oriented individual research projects that may hamper major scientific and technological breakthroughs, (2) the fostering of collaboration with stakeholders and problem-oriented research, and (3) encouragement of projects promoting inter- and transdisciplinary approaches for specific impacts forecast by the FORESTT program, in the framework of the open call.

The sheer size and the overarching goal of this PEPR will provide us with a unique opportunity to bring together critical mass, to increase understanding of the complex challenges of FORESTT and to overcome the bureaucratic and administrative barriers that impede innovative and "transformative" science. FORESTT will provide a long-term vision and direction for science (accompanied by a carefully-crafted implementation strategy with realistic outputs and expected outcomes), to ensure that the program can deliver on its promises around clear priorities and promote integrated approaches to research;

(ii) **Partnership-building** through the mobilization of a broad community of national stakeholders, and by fostering the transfer of scientific results to society. Increasing the awareness of the relevance of FORESTT scientific approaches among stakeholders is another important priority. However, the main challenge will be building a close partnership with representatives of national bodies from the forest sector, with the aim of aligning the scientific work with the development actions they support. FORESTT will achieve this objective, by leveraging on the living lab network, promoting innovation activities (through a dedicated fund for pre-maturation), and by building a partnership with the FCBA and the national Forestry and Wood cluster (Xylofutur), which brings together more than 250 professionals in the forestry and wood sectors, providing support for their innovation strategies. The raising of additional funds and leveraging on FORESTT resources will be given top priority;

(iii) **Fostering open science and embracing the digital transformation in forest sciences.** Our strategy is fully described in the NUM-DATA FP and is closely connected to the other four FPs;

(iv) **Innovative training programs** aiming to attain the program's education and training goals within the graduate school model, including the training of next-generation executives capable of dealing with forest issues (see FORESTT-HUB FP);

(v) **A dissemination and communication plan,** designed with the diversity of project results and end-users in mind. A digital communication platform will be embedded in the project website, to provide

the FORESTT scientific community with information (contents and schedules of calls for proposals, selected projects, data management and availability policies, etc.), to disseminate results to stakeholders and end-users (which should encourage their involvement in the program and the practical use of project outcomes), and to communicate with the general public. Face-to-face events will be favored at the local, national, and international scales, to maximize impact. An initial program launch meeting will bring together the various governance bodies to lay the foundations for success and to prepare the first project call. Two international conferences (when possible organized under the auspices of IUFRO) will be organized for the scientific community, in years 4 and 8. The conferences will target keynote speakers providing different or complementary perspectives on the main challenges of the FORESTT program. Last but not least, the proposed guidelines for open science (see NUM-DATA FP in connection with the four other FPs) will be shared at conferences within the international and national research community working on data interoperability, such as the Research Data Alliance (RDA) and its national node RDA-France or the Committee on Data of the International Science Council (CODATA).

(vi) **A knowledge transfer strategy**

Leading, systematizing and consolidating the interactive process of knowledge mobilization and transfer between stakeholders is a crucial challenge of the program. This involves not only identifying all the useful (from research but also from tacit and experiential knowledge) and relevant knowledge to be transferred (interaction between scientists and users, including those belonging to organizational and sociopolitical social systems), but also listening to the needs of the target audiences, in all their diversity (public policymakers, forest managers, other professionals in the forestry-wood sector, the media, the general public). For transformation of the best available knowledge and new scientific discoveries stemming from the program into economic, environmental and social impacts for the benefit of end-users in society, policy-making and industry, the strategy of the PEPR will be based on:

- The mandate of the GIP ECOFOR, the "transfer" component of which will be strengthened via FORESTT-HUB. The two directors of the PEPR held discussions with the scientific and administrative councils of the GIP in 2023 to support the transfer activities of its director;

- The relay organizations for which this is one of the missions (primary or secondary), such as 'RMT AFORCE', R&D network created in 2008 and specifically dedicated to these activities, the Fibois interprofessional organization, the R&D division of the ONF and CNPF, the IGN forest observatory coordination unit, the FCBA, and the IEFC, some of which will be represented on the National Stakeholders' Committee. More specifically, we intend to bridge the gap between scientific discovery and action by disseminating the knowledge acquired through dedicated publications in French, workshops to increase awareness among targeted stakeholders and to promote the integration of knowledge in professional practice, and professional training or demonstrations to facilitate knowledge exchange and the appropriation of results (see FORESTT-HUB WP4). In addition to this classical "push" model (transfer from researcher to users), we firmly believe that an "exchange" model, in which the two communities are jointly involved in generating knowledge and transferring research outputs, should be promoted in the open call. We will foster relationships between academic and private actors and citizens by making use of the living lab network (see FORESTT-HUB WP2). We will also rely on action-research and participatory science projects through open calls.

- The National Stakeholders' Committee, as part of the governance of the PEPR, to guide decision-making, help develop a transfer policy and facilitate the mobilization and use of knowledge in professional practices;

- Support for any initiative that promotes open science, such as financial participation in the "*Revue Forestière Française*", in return for the possibility of publishing a special issue each year

on the theme of the resilience of forest social-ecological systems. This alliance will encourage the wider dissemination of scientific knowledge;

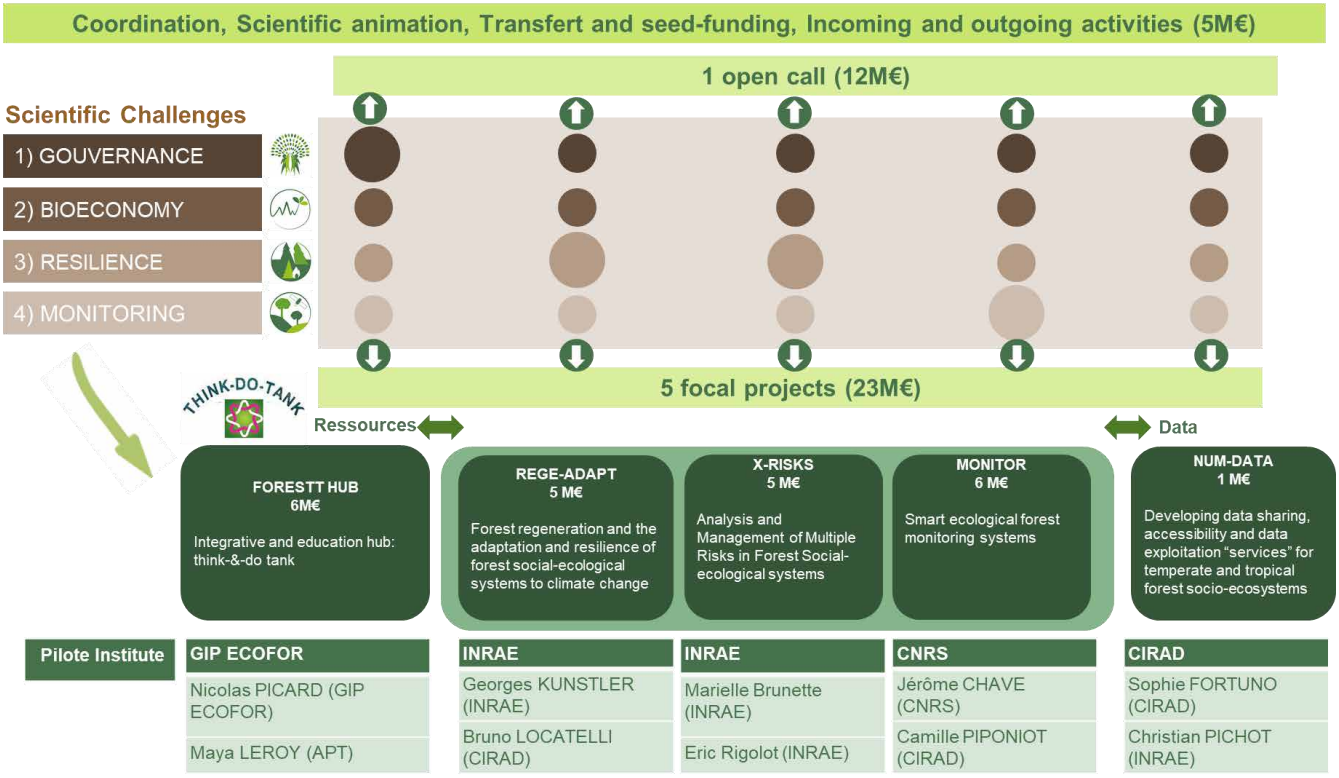
- Incentives, in the form of pre-maturation funds (€500,000, see section 3.2.3 pillar #7), will help to strengthen public-private sector partnership. We intend to use this instrument to advance towards bringing research results to fruition. In addition, thanks to its unique scientific environment and strong links to the socio-economic world, this program will seek to promote the emergence of CIFRE doctoral fellowships with joint supervision involving non-academic partners and focusing on FORESTT priorities.

3.2. PROGRAM DESCRIPTION

We have identified **four "2030 scientific challenges"** that support national (SNBC, SNDI, PNACC, PNFB, SNB), European (EU forest strategy) and global (SDG, UN) sustainable forest management and development commitments. As indicated in section 1.4, each scientific challenge is divided into well-defined **priorities driven by scientific excellence** in environmental, wood-based, and social sciences. As a means of facilitating the pursuit of cutting-edge research for these priorities and coordinating French research efforts to deliver the expected results of FORESTT, we propose to activate the **three levers (or program tools)** available within the framework of the PEPR ANR program: (i) pre-identified focal projects, (ii) one open call for collaborative research projects, and (iii) coordination actions, as shown in the figure below.

These research programmation levers are designed to facilitate the achievement of three overarching goals: (i) to generate and disseminate cutting-edge knowledge to fill identified gaps, (ii) to pool synergies and resources currently fragmented between research institutions, and (iii) to act locally and broadly by transmitting information to stakeholders and co-generating knowledge with them. The planned duration of the program is **7 years**. This duration will be required to **facilitate effective research collaboration between disciplines**, **to generate major scientific breakthroughs** and to **co-**

design innovations and decision support tools with stakeholders**,** policymakers and forest managers, to achieve the necessary transition of FSES.



3.2.1. Focal projects identified from the scientific road map of the PEPR

Focal projects (FPs) bring together interdisciplinary scientific communities that are sufficiently mature to tackle key challenges and provide transformative knowledge-based solutions to accompany the transition of forest social ecological systems. In the first version of the scoping document submitted in March 2023, five FPs were presented in a preliminary form. Since then, there has been a

participatory[15], inclusive[16] and transparent[17] consolidation process (much appreciated by the whole community), which took place from April to November 2023. This intense period of scientific animation offered a unique opportunity to engage stakeholders in the co-construction and co-implementation of the research priorities set within each FP. The FPs are now presented in a more advanced form[18];

For each FP, we provide a detailed description of the priorities addressed with respect to the scientific challenges of the PEPR, and specify the ways in which research forces are brought together and organized. The five FPs will be implemented over a seven-year period.

The overall budget allocated to the FPs amounts to about €23,000,000. As a means of tackling issues emerging during the course of the program not covered at the outset, each FP has earmarked flexible strategic funds to be dedicated to such new research questions.

As a means of ensuring the sustainability of newly established networks within each FP (e.g. in REGE-ADAPT: experimental network on the regeneration phase, in X-RISKS: systematic network for multi-risk analysis, in MONITOR: network of acoustic sensors and forest microclimatic conditions, permanent tree plots in French overseas territories, in FORESTT-HUB: network of living laboratories), the leaders

[15] Through participation in 30 workshops (750 connections), accompanied by the submission of expressions of interest (EI). The main characteristics of the EIs were as follows:
- **Thematic alignment:** an EI is a contribution (research action, mobilization of infrastructure; e.g. databases, networks of experimental or observation sites) that is aligned with the FP's research theme and contributes explicitly to one or more FP tasks or sub-tasks.
- **Voluntary contribution:** an EI is a voluntary contribution (individual or collective) to help the FP leaders consolidate a research programme. No budget is assigned to an EI..
- **Principle of co-design**: EI are at the heart of the FP's co-design. Contributors are invited to suggest how to refine the FP, how to integrate EIs into the FP (matchmaking) or, in the event of redundancy, how to combine EIs.
- **Structuring:** the EIs are proposed by the scientific community and the contributors are open to collaborations with other EIs in order to structure the FP's research activities. The proposed infrastructures must be open and the data must follow the FAIR principle.
- **Continuity:** EIs build on already established infrastructures and research networks and aim to have a lasting impact on the research community

[16] Everyone was invited to take part in the process of submitting expressions of interest, either individually or collectively

[17] Each EI was deposited in an open repository that could be consulted at any time by the scientific community. At the end of this self-expression process, FP leaders were called to present their synthesis to the scientific community.

[18] The texts describing the content of each FP have been concatenated and set aside in a dedicated report.

of each FP have been asked to develop a strategy aligned with institutional, national or international infrastructures for the duration of the program.

Last, but not least, early-career researchers have been associated with more senior researchers for FP coordination.

3.2.2. Open call for collaborative research projects

There are many research gaps, *i.e.* scientific challenge priorities not covered by the FPs. Thus, to open the program to innovative ideas and to promote inter- and transdisciplinary approaches, an open call for collaborative research projects will be launched in October 2024. For the identification of potential areas for improvement, the Executive Committee and the Internal Scientific Advisory Board will benchmark and evaluate similar programs in other countries aiming to bridge disciplinary divides.
Basic and applied research needs, complementary to and leveraging on the "services" provided by FPs, will emerge from three main channels that will feed the text of the open calls for proposals:

- Some research gaps identified during the scientific animations used to consolidate the FPs have been brought to the attention of the executive committee for further consideration in the the open call ;

- Other research topics little considered by a still unprepared community, have deliberately been identified as targets of active discussion. For example, a working group has been set up by the executive committee for the analysis of forest bioeconomy trajectories, with three axes of particular interest: (i) Integrating the dynamics of change in forest ecosystems (climate change, forest dieback, biodiversity loss, management practices, etc.) into methods for qualifying wood resources for end-uses adapted to markets and to the changing characteristics of the resource in the short, medium and long term, (ii) Going beyond the reductionist tension between 'supply' and 'demand' for wood and non-wood products and services, by analyzing the social-ecological conditions of coproduction for bio-economic activities and identifying

study problems relating to the socio-technical, geographic, socio-economic and political conditions of their development in synergy or competition, and (iii) Taking an interest in the diversity of bio-economic 'models' (wood and non-wood products) by considering the conditions for their coexistence from a multiscalar perspective and from local to global scales;

- A call for "expression of interest" will be open from Mai to June 2024. As a means of guiding brainstorming activities, the content of the scoping document (tis document) and FPs will be made available to the scientific community. Needless to say (i) the inclusion of ecological, social, economic and wood science researchers will be a prerequisite[19] for adoption of the FSES approach promoted within FORESTT, and (ii) these sessions will be open to decision-makers and stakeholders to generate ideas oriented towards the implementation of solutions that foster the transition of forests, forestry and value chains. The PEPR will increase the global visibility of these brainstorming activities (through web-based communication tools) and will provide financial support for the organization of face-to-face meetings. Hybrid configurations (with remote settings) will ensure that as many participants as possible can attend these sessions, especially those from overseas territories. The expected outcomes (a six-page summary of the proposed research priority) will be made available in a public repository and will constitute the “raw material” for a series of satellite workshops organized by the Internal Scientific Advisory Board and the Executive Committee during the scientific launch meeting of FORESTT in September 2024. The result of this consultation process will feed into the text of the open call launched in October 2024.

This open call for proposals will mobilize €12,000,000, with grants ranging from €850,000 to €1,200,000 per four-year project. Priority will be given to collaborative, original and innovative projects

[19] within a project, interdisciplinarity will be either considered within or between work packages.

taking conceptual or methodological risks, and encouraging researchers to propose high-risk high-gain projects and to develop interdisciplinary and transdisciplinary research. In particular, through the implementation of FPs, FORESTT will ensure that operational risks are covered by the use of existing (Appendix 7) or newly established research infrastructures managed by each FP and responsible for their maintenance or upgrading.

3.2.3. Program coordination actions

The coordination of the program is detailed in a specific document "FORESTT management and governance project" and summarized below. The budget for program coordination amounts to €5,000,000 and is structured into eight pillars:

- **Pillar 1. Program direction and scientific coordination**. Program coordination will be the responsibility of permanent members of INRAE, CIRAD and CNRS, who will form the PEPR Executive Committee (see governance scheme, section 3.9): namely the program Directors (Christophe Plomion and Arnaud Sergent – INRAE) and co-Directors (Jérôme Chave – CNRS, Daniel Barthélémy and Plinio Sist – CIRAD). These individuals will dedicate a significant amount of their working time to overseeing the implementation of the program strategy and achievement of its objectives, taking operational decisions concerning the running of the program, and liaising with the scientific community and national stakeholders. For science-related matters (e.g. organization of scientific events, preparation of open calls, annual project review), the Executive Committee will be supported by a Scientific Coordinator (Catherine Bastien – INRAE), who will also dedicate a significant amount of her time to the project.

- **Pillar 2. Technical coordination**. The program directors and scientific coordinator will be assisted by: (i) a program manager (Fanny Gascuel) recruited for the duration of the program to coordinate program organization and follow-up; (ii) a communications officer (Camille Lamy); and (iii) an

administrative and financial assistant. These last two individuals will spend 33% of their time on the FORESTT program (the rest of their working time being devoted to supporting other PEPR). These three people will be attached to the INRAE PEPR Support Service Unit (US 1502 PEPR) coordinated by Françoise d'Epenoux (INRAE).

- Pillar 3. Governance operations; A budget has been secured to cover governance costs: meetings and travels for the five governance bodies (see governance scheme section 3.8):

- The Executive Committee,
- The Internal Scientific Advisory Board,
- The Institutional Steering Committee,
- The National Stakeholders' Committee.

- Pillar 4. Open call. The first phase of the open call "call for expressions of interest" will be organized in spring 2024. The Executive Committee and the Internal Scientific Advisory Board will carry out an in-depth research-gap analysis promoting in particular (i) research topics identified during the establishment of FPs but not included in the FPs, (ii) research topics not yet included but that need to be addressed to respond to the four scientific priorities of the PEPR, and (iii) proposals from the national stakeholders and the scientific community on "interdisciplinary research topics" linked to the program objectives (see section 3.2.2). To support this first phase of collective brainstorming, the PEPR will provide financial support for organizing face-to-face meetings in spring 2024. The open call will be open in October 2024.

-Pillar 5. Scientific animation. Scientific animation will cover two main activities:

- **4.a. Consortium animation**. The operational team will organize national and international conferences throughout the program:
    - One launch meeting (political and scientific, in September 2024),

- annual FORESTT seminars (spring 2025, 2026, 2028, 2029) bringing together 150-200 attendees,
- Smaller thematic workshops and seminars associated with the transverse activities of focal projects (FPs) or other PEPRs, and projects financed through the two open calls for collaborative research projects,
- 1 international conferences (spring 2027), also overlapping with the annual FORESTT seminars.

- Pillar 6. International mobilities. The aim is to anchor French researchers in the international community, facilitate the dissemination of our tools and models, and train and master tools developed abroad to increase the relevance and scope of the tools, methods and databases developed and shared within the FORESTT framework. We will do this by providing funding opportunities for mobility grants (1 to 3 months), and contributing to the recruitment of administrative and financial assistants to organize mobility. Calls will be open once annually, and applications will be evaluated by the Internal Scientific Advisory Board and the Executive Committee.

- Incoming mobility will be organized by the CIRAD. Particular efforts will be made to promote the mobility of young faculty staff and PhD students from Mediterranean and tropical countries to enable them to come to FORESTT laboratories. Not only will this mobility foster international cooperation and increase the international visibility of the program, but it will also allow the supported research fellows to increase their scientific independence and improve their research profiles.
- Outgoing mobility will be organized by the CNRS. As a means of consolidating research teams able to meet the challenges of FORESTT, mobility grants will be available to enable scientists (with priority given to early-career researchers, PhD students and postdoctoral workers) to move from FORESTT laboratories to external laboratories to establish stronger bridges

between research units, to participate in international scientific schools or, when relevant, to participate in international initiatives (e.g. facilitating the proactive development of positions and strategies for important challenges relating to FSES transitions, preparation of COST actions relevant to the scientific priorities of FORESTT), and to attend international conferences (e.g. IUFRO tasks forces or working parties).

- Pillar 7. Communication, scientific outreach and open science. The FORESTT Management Office (see section 2.8) will organize and implement a communication strategy targeting the diverse audience of FORESTT. Communication tools will be designed to inform, communicate and disseminate the project results to the scientific community, national stakeholders and the broad general audience. These tools will include:

- Annual reports to the funding agency (ANR) and partner organizations (which will themselves relay information);
- A website (https://www.pepr-forestt.org/), which will allow communication on program progress, results and key events, calls for projects, calendars, etc., and which will be consolidated and extended as the program advances;
- Online videos of various formats, according to the targeted audience (which will be posted on the FORESTT YouTube channel, http://www.youtube.com/@PEPRFORESTT);
- A twice-yearly newsletter, together with a relevant mailing list;
- The animation of social media channels dedicated to FORESTT, to communicate with fellow scientists and engage with the public for communication, scientific mediation and science-in-culture events;
- Support for the "*Revue forestière française*", which will regularly provide visibility for FORESTT program outcomes;

- Scientific outreach initiatives (*e.g.* production of films, podcasts, exhibitions, serious games, etc.), focusing on PEPR research themes or interdisciplinary in nature (*e.g.* at the interface of arts and sciences with recruitment of Master's degree students to work on these projects);
- Participation in scientific events aimed at the general public (*e.g. "Fête de la science*", "*Tous chercheurs*");

- Pillar 8. Pre-maturation. FORESTT will identify research results ready for entry into a pre-maturation process and will assist valorization projects through existing initiatives and networks (such as the national ASTRAGAL consortium, or more local SATT[20] or university-based innovation initiatives), expertise developed by partner organizations (*e.g.* INRAE Transfer, CNRS Innovation, partner operating organizations, such as ONF and CNPF) or technological research centers (*e.g.* FCBA), or existing initiatives in universities and administrative regions. The valorization strategy of the PEPR will be defined in 2025, after a phase of identification and connection with existing initiatives, making use, in particular, of inputs from the National Stakeholders' Committee. This strategy may include:

- The recruitment of a valorization manager (ideally, recruitment jointly by FORESTT and the FCBA) responsible for identifying projects ready for pre-maturation, accompanying the development of these projects and assisting the researchers in their applications for transfer grants.
- The recruitment of "*Profils d'Interface*", as in recent years at ECODIV INRAE, to promote interfaces between research, development and innovation. In ECODIV INRAE, personnel from operational forestry organizations (ONF, CNPF, etc.) were recruited for 1 to 3 years to work part-time at INRAE, bringing researchers closer to innovation. Such contracts would here be devoted to topics related to forest resilience.

[20] Tech Transfer acceleration Companies

- Calls for pre-maturation projects linked to FORESTT priorities and requiring support for the recruitment of engineers or technicians, software development, field missions or the purchase of equipment. Co-funding with other pre-maturation initiatives, such as ASTRAGAL, would then be encouraged.

Carbon footprint. Last but not least, FORESTT will implement a strategy for minimizing the carbon footprint of its research activities and program management. This strategy will draw on methodologies currently being developed for quantifying the carbon footprint of research projects (contact with ADEME, Labo1.5 initiative, INRAE StopGES tool on this point).

3.3. INCLUSIVENESS OF THE PROGRAM

Four already funded exploratory PEPR have been considered to prevent undesirable duplications of research efforts and to promote synergies with FORESTT: (i) **FAIRCARBON**, relating to the contribution of forest systems to achieving carbon neutrality (the National low C strategy places the forest sector — *i.e.*, the C sink of forest ecosystems, substitution and storage capacity of wood products — at the heart of its strategy), (ii) **ONE-WATER**, relating to trade-offs between "green" and "blue" water. As forests play a critical role in supplying clean water, protecting and restoring forests is also an important priority for water security, (iii) **SOLU-BIOD** relating to nature-based solutions for the protection/restoration of forest ecosystems and the multiple services they provide, and **IRIMA** on the integrated management of natural risks.

The research priorities of FORESTT were also developed taking into account all major initiatives already funded at the national (*e.g.* new ANR projects, LabEx ARBRE, CEBA, AGRO, CEMEB, NUMEV) and European (see Appendix 9) levels. FORESTT leadership will leverage national (GDR on wood sciences) and international (IUFRO task forces, IUFRO working parties, EPSO, COST actions) working groups and networks, in which French researchers have taken a leading role. The FORESTT-hub in FP#4 will also

foster collaboration with the French Synthesis Centre for Biodiversity (FRB-CESAB). Strategic links, favoring synergistic actions with these initiatives, will be established by the executive committee of FORESTT, providing ample opportunities for cooperation at the national and international levels.

3.4. EXPECTED OUTCOMES: WHAT WILL FORESTT ACHIEVE BY 2030?

A first set of **expected outcomes** of FORESTT will be the production of **cutting-edge integrated knowledge and the dissemination of tangible results articulated around its five research challenges**. These outcomes (see, in Appendix 10, the list of **expected outcomes** attached to each scientific challenge and the lists attached to each Focal Project) will provide valuable data, resources, models, scenarios and recommendations to help stakeholders make strategic choices and prepare the forest sector for a future of increasing global risks and uncertainties, ensuring a successful transition towards resilient future forests.

A second major expected outcome relates to **the way knowledge is produced** with respect to complex social and environmental issues, transferred to stakeholders and finally transformed into innovation actions with longer-term impacts in the forest sector. FORESTT will help (i) to break down barriers between disciplines, making it possible to address integrated research questions collectively and to identify unmet research and innovation needs, (ii) to develop the use of innovative research and innovation methods, and (iii) to reshape graduate training programs to improve the balance between interdisciplinary breadth and intradisciplinary depth, thereby enabling students to develop a particular area of expertise, while also providing first-hand experiences to help students to function effectively within interdisciplinary teams.

3.5. TIMETABLE FOR IMPLEMENTATION OF THE PROGRAM

2023 has seen an intense preparatory phase:

- **Step#1:** Initial submission of this proposal (March and December2023),

- **Step#2:** Information of the scientific community (three webinars organized in March 2023) and national stakeholders (two webinars organized in November 2023) about the objectives and scope of FORESTT, the setting up of the various governance committees (still underway) and consolidation of the five focal projects (May-Nov. 2023).

The next important steps, which will take place in the 2024 and 2025 will be:

- **Step#3**: Launch of the five focal projects (in 2024 for a six-year period), political and scientific launches of the PEPR (September 2024), development (May-June 2024) and publication (October 2024) of the open call for collaborative projects,
- **Step#4**: Implementation of the 1st wave of collaborative projects (starting in June 2025 for a four-year period), 1st internal FP review, annual meeting and ANR evaluation,

3.6. COMPLIANCE WITH ANR STANDARDS

Throughout the course of the program, FORESTT is committed to respecting ANR standards concerning gender equality, scientific ethics, and the plan for open science. Particular attention will also be paid to reducing the carbon footprint of research activities.

3.7. PROJECT FOLLOW-UP

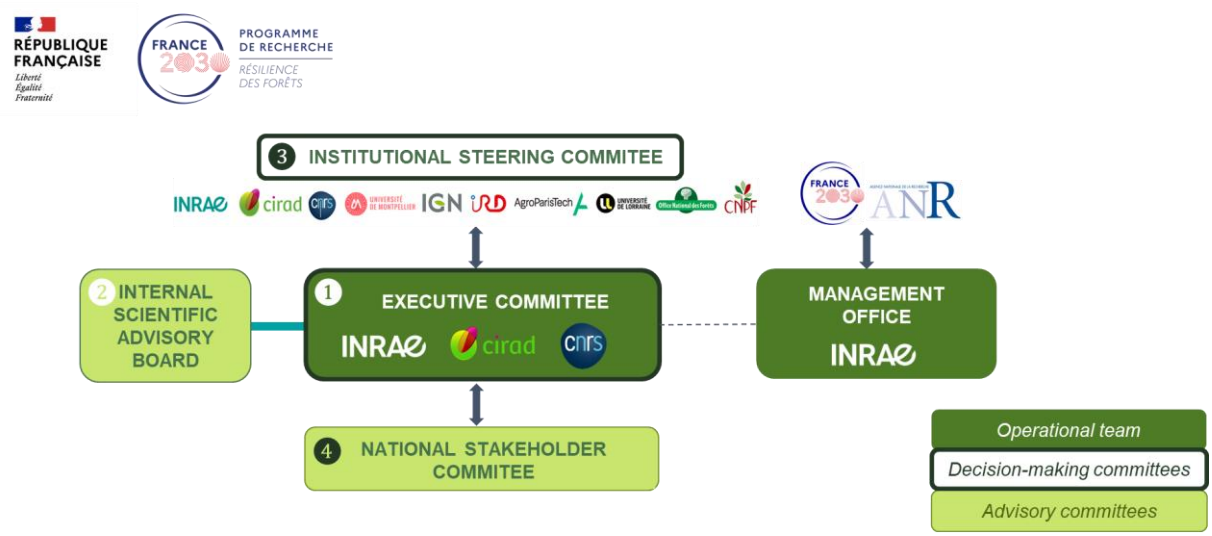
Progress (on a yearly basis) and final reports will be validated by the Institutional Steering Committee, outlining the achievements and difficulties encountered and proposing changes. These reports will precede the activity review for the ANR program every other year. A list of progress and performance indicators (PPI) will be established (in coordination with the ANR and the France 2030 committees) to monitor efficacy and efficiency in terms of expected program outputs and impacts. We will comply with these indicators over the eight-year period.

3.8. PROGRAM FUNDING ALLOCATION

The budget requested for FORESTT amounts to €40,000,000 over seven years (Jan 2024-Dec. 2030. Following ANR rules for the PEPR program, a 20% flat-rate charge will be applied to cover the beneficiary's overheads.

3.9. GOVERNANCE

The governance of the FORESTT program (figure below) will be based on following interconnected bodies:



I) The operational team has two components:

The **Executive Committee** is responsible for making all decisions required for the coordination and smooth implementation of the program. It oversees implementation of the strategy and achievement of the objectives, communicates and reports to the other committees, and ensures that the program is open to the entire national scientific community. It comprises the INRAE directors of PEPR (Christophe Plomion and Arnaud Sergent), accompanied by a program manager (Fanny Gascuel), and members from CIRAD (Plinio Sist and Daniel Barthélémy) and CNRS (Jérôme Chave). It meets weekly,

and the attendees are extended every two months to representatives of the three supervisory institutions for the discussion and validation of operational orientations (for INRAE, Françoise d'Epenoux - Director of the PEPR support unit; for CIRAD, Sandra Vander Stuyft - Deputy Director of the *Environnements et Sociétés* department; for CNRS, Frédéric Villieras - Director of the national programs mission). The Executive Committee works closely with the ANR PEPR manager (Virginie Baldy) and with the interministerial task force (MESRI, DGPI, MTECT, MASA) associated with the CPMo.

The Executive Committee will be assisted by a **Management Office** coordinated by Françoise Ruffier-d'Epenoux, with a project manager (Fanny Gascuel) recruited for the duration of the program. Operated by INRAE centrally for several PEPRs, this structure will be responsible for the administrative, financial, legal, communication and dissemination aspects of the FORESTT program. It will also organize meetings and conferences and provide support for reporting.

II) The Internal Scientific Advisory Board has an advisory role. It is chaired by Catherine Bastien (INRAE) and comprises a group of French experts, with a balanced gender distribution, from different scientific institutions, with recognized and complementary skills. This committee guides the scientific strategy (by participating in drafting open calls, identifying areas for improvement and benchmarking similar initiatives worldwide to foster collaboration with FORESTT), monitors the progress of focal and collaborative projects, and provides opinions concerning the quality and relevance of the research carried out (by regularly interviewing scientific project leaders). It will also help the Executive Committee to develop a recruitment strategy for early-career researchers (ECRs), by targeting ECRs to run some of the workshops, for example, facilitating the emergence of "interdisciplinary research topics" for the open calls.

III) Institutional Steering Committee, which is involved in decision-making, together with the Executive Committee, includes key institutions representing national research organizations and higher educational and research institutions strongly involved in forest-related research in France and

in tropical areas (INRAE, CIRAD, CNRS, IRD, UM, UL, APT, IGN, ONF, CNPF). Chaired by INRAE, the CEOs of these different institutions (or their representatives) will take decisions concerning the strategic orientations of the program. They will meet annually to define, prioritize and validate the scientific orientations proposed by the Executive Committee (including changes in scientific strategy, the prioritization of actions, and resource allocation) and will ensure that these orientations fit in with the strategies of their institutions, and serve the scientific community as a whole. Their decisions will not only be based on the Executive Committee proposals, but also on the opinions issued by the National Stakeholders' Committee and the International Scientific Committee. Decision-making procedures will be established early in 2024, in consultation with all members.

IV) National Stakeholders' Committee, including a wide range of players from industry and society as only stakeholders with multiple types of expertise open to many forms of knowledge can effectively meet the challenges facing forest socio-ecosystems. This committee will stimulate the integration of stakeholders into the program, and convey the views, needs and concerns of stakeholders on PEPR's research themes. It will be a space for (i) discussing scientific programming issues and prioritizing prospective proposals within the framework of the PEPR, and (ii) identifying research results ready to enter the pre-maturation process. It will, thus, play a key role in the rapid evaluation of implementation opportunities and in ensuring that the expected outcomes lead to transformative changes.

3.10. SCIENTIFIC PROFILES OF THE DIRECTORS AND CO-DIRECTORS OF THE FOREST PROGRAM

Christophe PLOMION (senior scientist, INRAE) has published 190 peer-reviewed articles and several books (H-index = 71 - 14,000 citations, Google scholar). Since 2019, he has been Director of the BIOGECO research unit (INRAE, Bordeaux University). As Scientific Deputy Director of the Ecology Division of INRAE (from 2008-2018) he had scientific and strategic responsibility for 30 research laboratories. He has extensive experience in the management of large national and European projects

(coordination of 30 projects) and has coordinated an IUFRO working party for five years. He has repeatedly acted as a reviewer of research projects for Genome Canada, NSF, the European Commission, the ANR and the Finnish Academy. He is currently Associate Editor-in-Chief of the Journal Tree Physiology.

Daniel BARTHELEMY (senior scientist, CIRAD) has contributed to many books and publications including more than 80 peer-reviewed articles (H-index = 40 - 5,770 citations, Google scholar). He has served as Director of the AMAP research unit (2000-2010) and Head of the Biological Systems (BIOS) Division of CIRAD (2010-2018). He is currently Head of the Agriculture, Environment, Biodiversity Research Cluster (responsible for about 3,000 permanent staff and 45 research units) at the Montpellier University /Program of Excellence, I-site.

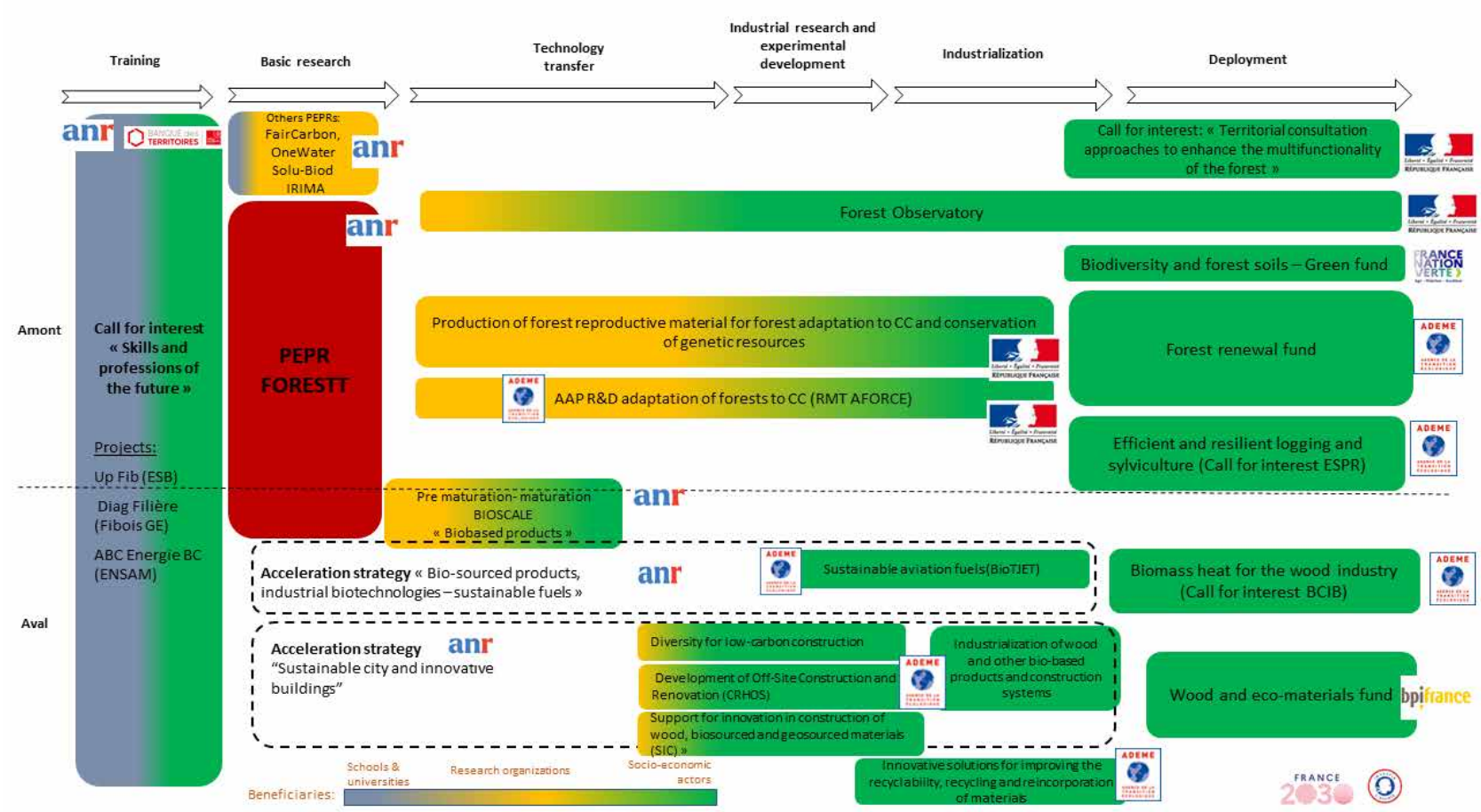
Arnaud SERGENT is a research engineer in political science and Head of the Forest Social Science and Economics team at the ETTIS INRAE research unit. He has led and participated in various multidisciplinary research projects on integrated forest management, forest carbon governance and bioeconomics, and has also conducted many assessments of forest related policy (For ADEME and the Ministry of agriculture). From 2016 to 2020, he was Head of the Scientific Council of the national "Forest & Wood" cluster Xylofutur and, since 2021, he has been coordinating the regional forest-wood research network in New Aquitaine.

Plinio SIST (senior scientist, CIRAD) has published 150 publications (H-index = 38 - 6,240 citations, Google scholar). His skills are in tropical forest ecology with over 30 years of experience in South America and Southeast Asia. He is Director of the Forests and Societies research unit, and he has expertise in tropical forest ecology. He has coordinated research and development projects for the EU and the French Global Environment Facility. He is part of the Science Panel created under the auspices of the Sustainable Development Solutions Network, which brings together more than 150 scientists responsible for publishing the first scientific report on the state of the Amazon basin.

Jérôme Chave (senior scientist, CNRS) is a researcher in ecology and evolution, and head of the Evolution et Diversité Biologique research unit in Toulouse (100 staff). His research has contributed to theoretical ecology, remote sensing, biodiversity, and vegetation modeling. He coordinates the laboratory of excellence CEBA on Amazonian biodiversity (18 M€ funding), and is a member of European Space Agency programs on forest biomass. He has published over 120 papers (H-index = 97, >51,000 citations, Google scholar) and is a coauthor of the *World Atlas of Trees and Forests* (Princeton University Press, 2022).

APPENDICES

APPENDIX 1 - POSITIONING OF THE FORESTT PROGRAM IN THE MULTI-FACETED 'FRANCE 2030' NATIONAL STRATEGY ON FOREST AND WOOD-BASED INDUSTRY



APPENDIX 2 – LIST OF MAIN ACRONYMS

ADEME: The French Agency for Ecological Transition

AFORCE: Adaptation of forests to climate change

Agreenium: Alliance of training and research for agriculture, food, environment and global health

AgroParisTech: Institute of life and environment sciences and industries

AnaEE France: Analyses and experimentation for French ecosystems

APC: Article Processing Charge

APCA : Permanent assembly of the chambers of agriculture

ARBRE: Advanced research on tree and forest ecosystem biology

ATGeRI: Territorial planning and risk management

BPI France: The French public investment bank

CA72: The Sarthe Chamber of Agriculture

CAS: Chinese Academy of Science

CEA: The French atomic and alternative energy commission

CEBA: The study center for Amazonian biodiversity

COST: European Cooperation in Science and technology

CRITT: Regional innovation and technology transfer center

CSF: Strategic committee for the wood sector

CSIC: Consejo Superior de Investigaciones Científicas

CSFB: National Council of Forestry and Timber

CSTB: Scientific and technical center for the building industry

CTP: Technical center for paper

DATA TERRA: Data and service centers for the terrestrial system

DFCI: Forest fire defenses

EFF: French forestry experts

EHESS: School for advanced studies in social sciences

ENS-PSL: École normale supérieure (Paris)

ENSAIA: The national school for agronomy and the food industry

ENSAM: The national school for trades and crafts

ENSAT: The national school for agronomy of Toulouse

ENSG: The national school for geographic sciences

CEMEB: The Mediterranean center for the environment and biodiversity

CESAB-FRB: Center for synthesis and analysis on biodiversity

CIFOR: Center for International Forestry Research

CIRAD: International center for cooperation in agronomic research for development

CNES: The national center for space studies

CNPF: The national forest ownership center

CNRS: The national scientific research center

CPFA: The forest productivity and action center of Aquitaine

CODIFAB: Professional Committee for Economic Development of wood and furniture industries

CSF: Contrat stratégique de Filière bois

FCBA: Technological Institute of Forestry, Cellulose and Wood Construction

Fransylva: National association of private forest owners

FRB: The foundation for research on biodiversity

FSC: Forest Stewardship Council

FSES: Forest social-ecological systems

GCF: Forestry cooperation group

ENSTIB: The national school for wood technologies and industries

EPHE: The school for advanced practical studies

EPIC: Public establishment of an industrial or commercial nature in France

EPST: Public establishment of a scientific and technological nature

ES: Ecosystem services

ESA: European Space Agency

ESB: The wood school

FAIR: Findable Accessible Interoperable Reusable

FBF: interprofessional organization “France Bois Forêts”

FBIE: Interprofessional organization “France Bois Industrie Entreprises”

FNE: French environmental NGO (“*France Nature Environnement*”)

ONIRIS: National Veterinary, Food and Agriculture School of Nantes-Atlantique

ORCHIDEE: Organizing Carbon and Hydrology in Dynamic Ecosystems

PEFC: Program for the Endorsement of Forest Certifications

PEPR: Priority Research Programs and Equipment

GDR: CNRS research grouping

GIP: A grouping of public interest

GIS: A grouping of scientific interest

ICOS: Integrated carbon observation system

IEFC: The European institute for cultivated forests

IGN: The national institute of geographic and forestry information

INP: The national polytechnic institute

INRAE: National institute for research on agriculture, food and the environment

IRD: Research Institute for Sustainable Development

IUFRO: International Union of Forest Research Organizations

LabEx: Laboratory of excellence

Lidar: Laser imaging detection and ranging

LPO: League for the Protection of Birds

LULUCF: Land Use, Land-Use Change and Forestry

MAA: Ministry of agriculture and food

MI: Ministry of Home Affairs

MNHN: Natural History Museum in Paris

MTE: Ministry of Ecologcial Transition

PNACC: National programme for adaptation to climate change

PNFB: National Forest and Wood Program

RENECOFOR: National network for long-term monitoring of forest ecosystems

RMT: Réseau Mixte Technologique

RNF: Association of nature reserve

RZA: Réseau des zones ateliers

SCAR: Standing Committee on Agricultural Research of the EU

SDG: Sustainable Development Goal

SDIS: Service Départemental d'Incendie et de Secours

sDIV: The Synthesis Centre for Biodiversity Sciences

SES: Social-Ecological System

SFCD: Société Forestière de la Caisse des dépôts

SFM: Sustainable Forest Management

SLU: Swedish University of Agricultural Sciences

SNB: National Biodiversity Strategy

SNBC: National Low Carbon Strategy

SNDI: National Strategy to Combat Displaced Deforestation

SSE: Social sciences and economics

NA: Nouvelle-Aquitaine **NCEAS:** National Center for Ecological Analysis and Synthesis **NGO**: Non-governmental organization **NSF**: National Science Foundation **NUMEV**: Solutions numériques, matérielles et modélisation pour l'environnement et le vivant **OFB**: National office of biodiversity **ONF**: National office of Forests	**SWOT**: Strengths Weaknesses Opportunities Threats **IUCN:** International Union for Conservation of Nature **UMR**: Joint research unit **USDA**: United States Department of Agriculture **VEM:** Business intelligence for the wood-based sector **WWF:** World Wildlife Fund

APPENDIX 3 – REFERENCES

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APPENDIX 4 – FORESTT RESEARCH COMMUNITY AND RELEVANT EXISTING COLLABORATIVE TOOLS FOR RESEARCH, DEVELOPMENT AND TRANSFER

(a) List of national research organizations, higher education and research Institutions, Research-Development & Innovation services in operating organizations. In bold, partner institutions involved in the FORESTT Institutional Steering Committee. The size of the organization (number of permanent researchers) in the forest domain is indicated by bullets: ● < 10; 10 ≤ ●● < 30; 30 ≤ ●●● < 75; ●●●● ≥ 75

<table>
<tr><th>DOMAINS: forest ecology, forestry, wood sciences, and environmental sciences</th><th>DOMAINS: social sciences and economics</th></tr>
<tr><td colspan="2">National research organizations</td></tr>
<tr><td colspan="2">CIRAD ●●●●, CNRS ●●●●, INRAE ●●●●, IRD ●●●, MNHN ●●●, CNES ●, CEA ●</td></tr>
<tr><td colspan="2">Higher education and research institutions</td></tr>
<tr><td colspan="2">AgroParisTech ●●, Lorraine Univ. ●●●, Montpellier Univ. ●●●, Paris Saclay Univ. ●●, Grenoble Alpes Univ. ●</td></tr>
<tr><td>Institut Agro: Agrocampus Ouest and Montpellier SupAgro ●, Bordeaux Sciences Agro ●, ENSTIB ●●, ESB ●, ENSAM Arts et Métiers ●, CentraleSupélec ●, ENS-PSL ●, INP Toulouse ●, Bordeaux Univ. ●●●, Toulouse Univ. ●●●, Picardie Univ. ●, Rouen Univ. ●, Aix-Marseille Univ. ●●, Limoges Univ. ●, Clermont-Auvergne Univ. ●●, Orléans Univ. ●●, Guyane Univ. ●</td><td>EHESS ●, ENSG Géomatique ●●, EPHE ●●, Paris Dauphine Univ. ●, Paris-Est Univ. ●, Pau et des Pays de l’Adour Univ. ●, Gustave Eiffel Univ. ●, Caen Univ. ●, Sorbonne Univ. ●●</td></tr>
<tr><td colspan="2">RD&I services in operating organizations</td></tr>
<tr><td colspan="2">ONF (public forest) ●●●, CNPF (private forest) ●●●, IGN (forest inventory) ●, Météo-France ●, OFB (biodiv.) ●, FCBA●●●●</td></tr>
<tr><td colspan="2">Multiple partnership structures</td></tr>
</table>

GIP **ECOFOR** (AgroParisTech, CIRAD, CNPF, CNRS, FCBA, IGN, INRAE, IRD, MNHN, ONF, MAA, MTE) ●, GIP **ATGeRi** (MAA, MI, MTE, Région NA, DFCIs, SDISs, ONF, IGN, Syndicat des sylviculteurs Sud-Ouest, …) ●, **Agreenium** (AgroParisTech, AgroSup Dijon, Bordeaux Sciences Agro, Ecole Nationale Vétérinaire de Toulouse, Institut Agro, Montpellier SupAgro, Oniris, Toulouse INP-ENSAT, ENSAIA, ENSTIB, VetAgro Sup, INRAE, Cirad) ●, Xylofutur (Forestry & Wood Cluster) ●	
GDR Wood Sciences (24 universities, 12 higher education institutions, 10 research organizations, 30 companies from the wood industrial sector) ●, **RMT AFORCE** (AgroParisTech, FCBA, GIP Ecofor, IEFC, INRAE, Météo-France, CNPF, ONF, IGN, SFCD, EFF, GCF, APCA, CA72, Lycée Meymac, Lycée Mirecourt) ●, **GIS Groupe Pin maritime du futur** (CNPF, CPFA, FCBA, INRAE, ONF) ●, **GIS Coop Données de Croissance des peuplements forestiers** (AgroParisTech, CNPF, CPFA, FCBA, INRAE, ONF, MAA) ●, **GIS Peuplier** (FCBA, INRAE) ●	

(b) Relevant Research and Education Programs for FORESTT: Labex AGRO – Agronomy and sustainable development (Montpellier); ARBRE – Advanced research on the biology of tree and forest ecosystems (Nancy); CEBA – Center for the study of biodiversity in Amazonia (French Guiana); CEMEB – Mediterranean center for environment and biodiversity (Montpellier); NUMEV – Numerical, material and modeling solutions for the environment and life (Montpellier).

APPENDIX 5 - EXTENDED SWOT ANALYSIS

STRENGTHS (1) An excellent and internationally visible scientific community on forest ecosystems and wood science. A bibliometric analysis of academic production over the period 2011-2020 shows that French forestry research ranks 9th in the world and 4th in Europe. Three French institutions are among the top 20 in forest research globally, with the CNRS ranking 3rd in the world (1st in Europe), INRAE ranking 6th in the world (2nd in Europe), and IRD ranking 18th in the world (6th in Europe). French scientific publications on forests are characterized by a high proportion of international collaborations (75% of publications, versus 31% for total publications worldwide). **(2) Strong centers** (in Nancy, Bordeaux, and Montpellier) **of forest research connected to forested territories and education. (3) Research into a diverse range of forest ecosystems.** One third of French forests (8M ha) are tropical overseas forests, and there is a dynamic French forest research center in French Guiana (UMR ECOFOG). French research on tropical forests is highly reputed, ranking 8th in the world (3rd in Europe). Five French research institutions rank in the top 20 for tropical forest research: CNRS (3rd in the world), INRAE (6th), IRD (7th), CIRAD (10th) and Montpellier University (11th). These institutions are the only European research institutions ranked in the top 20 most cited research institutions in the field of tropical forestry. **(4) A set of research infrastructures registered on the national roadmap in support of FORESTT activities.** Long-term environmental facilities combining observation and experimentation have been developed by French research institutions over many decades, in close collaboration with public and private forest managers. Many of these facilities are now part of national (IN-SYLVA France) or European (AnaEE France and ICOS-France the French nodes of ANAEE and ICOS; RZA and OZCAR two French nodes of e-LTER) research infrastructures. They also include analytical facilities (dedicated to wood: PHENOBOIS and SilvaTech, soil: INFOSOL, and genomics: Genomics) and e-infrastructures (federated around the GAI DATA hub) complying with an open-science and FAIR data policy. They provide unique conditions for the validation of technological advances before larger-scale deployment and for the development of more systemic research on local challenges.

WEAKNESSES. **(1) Environmental and material sciences are poorly connected with humanities and social sciences in French research, and research capacity is not evenly spread between disciplines**. Forests are the main research focus of a few research units, but most research institutions and UMRs focus on systemic topics, of which forests are just one element. Within a research institution, researchers working on forests are usually spread across multiple research units addressing different systemic topics, and they interact very little. In material sciences, social sciences and economics, the global complexity of forest issues is poorly understood, despite being addressed by a diversity of units. **(2) The transfer of knowledge and knowhow must be accelerated**. Some applied forest research (performed by about 80 researchers in total) is performed in institutions responsible for managing public or private forests (*i.e.* ONF and CNPF, respectively) or for monitoring forests (IGN, Forest Health Division of the Ministry of Agriculture). One Joint Technology Network on Forest Adaptation (RMT AFORCE) and several technological centers (Appendix 4) also ensure knowledge transfer from science to development, but this organization is much smaller than its counterparts in the agricultural sector, despite the recognition of French capacities in forest bioeconomics research and innovation in Europe. This segment of the forest research community is important to ensure the continuity of knowledge transfer from pure research to forest management and forestry practices, but it requires strengthening. Conversely, communication from foresters to scientists also needs improving, to enable scientists to understand the challenges facing foresters and to help decrease the reticence of foresters to change their practices.

THREATS. **Total national public funding for forest and wood research** is just over €200M/year (2015 estimate). This amount **corresponds to only a small percentage of the total value generated by the forest and wood sector** (about 1% of the total added value or 0.35% of total turnover, [11]). More than half this funding effort covers staff costs at research institutions, and more than a quarter corresponds to tax credits. The funding of research projects through project calls from French funding agencies (ANR, ADEME, and BPI-france) accounts for just under 10% of total funding, whereas European funding

through Horizon 2020 accounts for 2.5% of total funding. The main French research funding agency, ANR, provided €67.7M to support research projects on forest and/or wood over the 2005-2018 period, including €8.7M joint funding in the framework of ERA-NETs and international partnerships. INRAE is the French research institution that has received the most forest-related funding from the ANR. In forest-based bioeconomics, French funding for research is reasonably generous with respect to other European countries (ranked 4th in the EU). However, when this funding effort is expressed per unit of forest area or per unit of wood harvest, France is among the lowest ranked of all European countries [107].

OPPORTUNITIES. (1) FORESTT is aligned with national and international political commitments concerning the role of forests in mitigating the impact of global change and in achieving sustainable development goals, **(2) European research programs should enable the French forest research community to gain momentum in its attempts to address global challenges**. Indeed, French forest research already plays a leading role in European (Appendix 9) and international forest research. France has played a significant part in all four forest-based ERA-NETs and in the working group on forests of the SCAR. About one quarter of the forest relating projects funded by ANR in the 2010-2018 period involved research units from other countries, with German partners most frequent, followed by Swedish and Spanish partners. In forest-based bioeconomics, French research is ranked 5th among European countries, and INRAE is a key institution in European networks [107]. French research institutions have close relationships with the European Forest Institute and with the Joint Research Center of the EU. They also have close relationships, including seconded positions, with CIFOR and FAO for forest-related issues. French researchers are strongly involved in IUFRO, where they lead or co-lead two divisions and seven units. **(3) The French forest research community is familiar with knowledge integration across disciplines and scales**. Several cross-institutional instruments are already establishing consistency and synergies between French research institutions on forest-related topics. These instruments are research animation structures (LabEx, GDR), groupings of public interest (GIP,

see Appendix 6), and groupings of scientific interest (GIS), or research infrastructures (see Appendix 7 for details). **(4) Innovative education and training are key assets for fostering transformative changes.** Care must therefore be taken to ensure that interdisciplinary training programs allow students to function effectively within interdisciplinary teams, and to strengthen the links between the research community and the main forest education centers.

APPENDIX 6 – GIP ECOFOR IN SHORT

The grouping of public interest (GIP) "**ECOFOR** (Forest ecosystems)", brings together **12 French public institutions** involved in forest research, *i.e.* forest research organizations (CIRAD, CNRS, INRAE, IRD), higher education and research institutions (AgroParisTech, MNHN), forestry organizations, including research departments (CNPF, IGN, ONF), technological research centers (FCBA) and ministries responsible for forests (Ministry of Agriculture and Food, Ministry of Ecological Transition).

The mandate of GIP ECOFOR is to develop, gather, and organize scientific knowledge to support public policies and sustainable forest management practices in temperate and tropical biomes. This GIP provides the necessary means for performing and promoting research and expertise on the functioning and management of forest ecosystems. It is well-suited to studies on issues involving several of its members, requiring a high degree of interdisciplinarity, and connecting science and decision-making, forestry and other sectors, or forestry issues and major environmental issues. ECOFOR operates at the international, national and regional scales.

The GIP ECOFOR is active in **four thematic areas**:

- Biodiversity and ecosystem functioning;
- Risks and climate change;
- Ecosystem services and sustainable forest management;
- Information systems and forest research infrastructures.

The GIP ECOFOR has **four main modes of action**:

- Providing collective scientific and technical expertise, to generate state-of-the-art answers to complex questions on forests and to identify knowledge gaps;
- Performing foresight analyses and defining emerging topics in forest research;
- Leading and accompanying research programs;

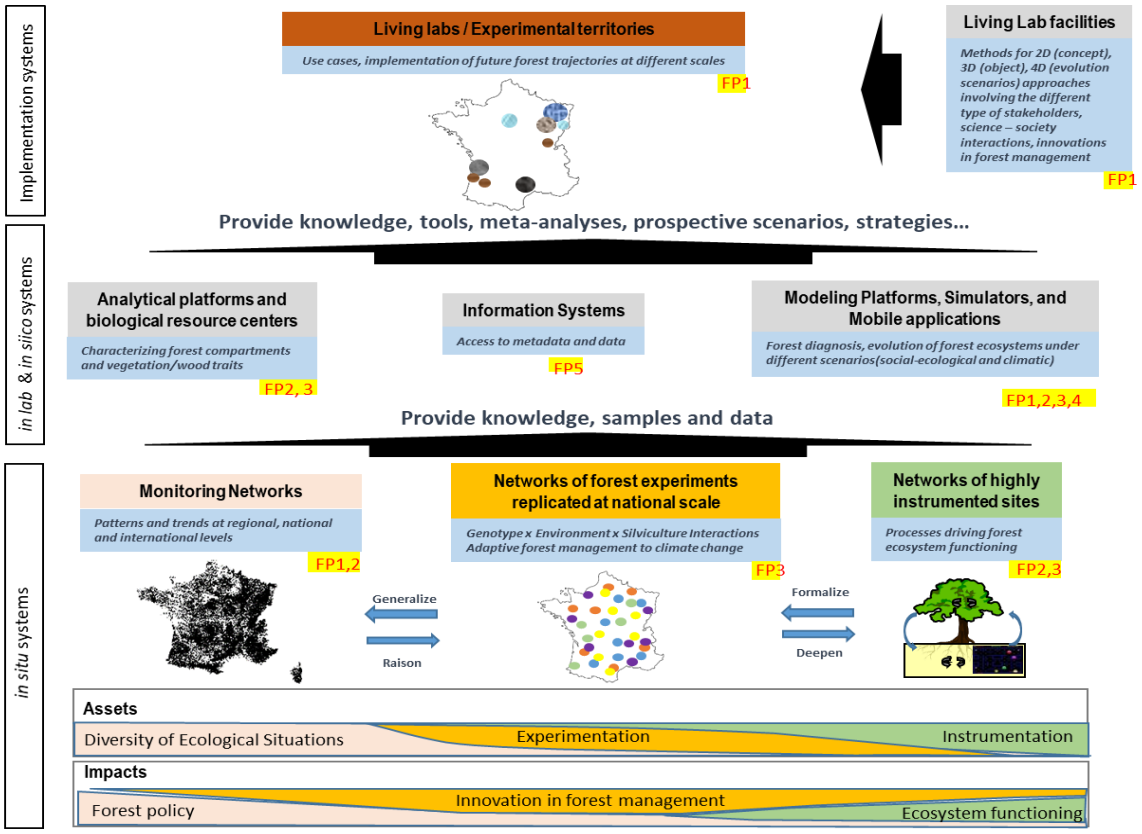
- Evaluating, disseminating and promoting scientific knowledge obtained in studies and projects through tools such as seminars, conferences, and books.

ECOFOR was established in 1993 as an implementation of the resolution of the 1st Ministerial Conference on the Protection of Forests in Europe to "organize a mechanism for national cooperation — on research into forest ecosystems — in the framework of its own appropriate structures, and then, to participate in the international activity of this network, together with the other countries". It was renewed in 2003 and 2013.

More information: http://www.gip-ecofor.org/

APPENDIX 7 - LIST OF EXISTING RESEARCH INFRASTRUCTURES

Mapping on FORESTT focal projects (FP); international partnerships are indicated by a globe. Abbreviations for the various categories of infrastructures are as follows: O, observation, E, experimentation; RS, remote sensing.



Details for *in situ* systems and Living-Labs

Monitoring Networks		
IFN	(O, RS). Permanent inventory of national forest resources- 35000 plots, 7000/year	
DSF	(O). Monitoring, diagnostic and phytosanitary advisory system. 200 field observers	
ICP Forest	(O). Int. Coop. Progr. on Assessment and Monitoring of Air Pollution Effects on Forests.	🌍
RENECOFOR	(O). Long-term monitoring of managed forest ecosystems in mainland France. 102 plots (ICP-Forests, Level II)	🌍
RMQS	(O). The Soil Quality Measurement Network: a long-term soil monitoring tool. 2240 plots	
RESOFOP	(O). Socio-economic survey data collected on large panels of French private forest owners	
Int. Tree Mortality Network	(O). IUFRO task force on tree mortality	🌍
GUYAFOR	(O). Permanent-plot monitoring of forest dynamics and biodiversity (54 plots in French Guiana)	
Networks of forest experiments replicated at national & international scales		
IN-SYLVA France	National research infrastructures (RI) for adaptive management in forests. 27 *in natura* networks, 5000 plots	
	(O, E). Forest Genetic Resources (from seed orchards, to provenance and species) - 7 networks, **1355** plots	🌍
	(O, E). Forest Genetic Resources and stand management (mixing both factors) - 4 networks, **3690** plots	
	(O, E). Stand regeneration and forest ungulate interactions - 5 networks, **33** plots	
	(O, E). Stand management (spacing, logging, mixed stands,..) - 7 networks, **344** plots	🌍
	(O, E). Soil management (species, amendment, logging residues) - 4 networks, 79 plots	🌍
Networks of highly instrumented sites		
ICOS France	(O, RS). National RI. Standardized greenhouse gas measurements – 24 in France, 7 sites in forests	🌍
RZA LSTER France	(O, E). National RI. Long -term Social Ecological Research- 14 landscapes in France	🌍
AnaEE France	National RI. Complex interactions between ecosystem components. 33 sites, 13 in forests	🌍
	(O, E). Soil Management (soil compaction and tree species) - 2 sites	
	(O, E). Stand management (mixed species, intensity of harvesting/tapping for rubber trees) - 7 sites	
	(O, E). Drought experiments - 4 sites	
Living labs / Experimental territories		
Des Hommes et des Arbres	Living Lab - Network of territorial projects connected with Living Lab facilities in the North-East of France (oak, spruce and fir dieback)	
	(O, RS) National regional park: PNR Vosges du Nord et Ballons des Vosges & PETR du Pays de la Déodatie (about 1000km2 each)	
	(O, E, RS) Vallée de la Doller (small territory – 100km2)	
	(O, E, RS) Darney la Voge, Forêt de la Harth (forest scale –15000 & 13000 ha)	
Forest Bocage	(O, E). Landscape scale (40 000 ha) – Degraded forest ecosystem restoration – South-West of France	
PNR du Haut languedoc	(O). National regional park (3000 km2) – Energetical and ecological transitions - South-east of France of France	
Forêt de Chantilly	(O, E). Forest scale (6000ha) – Oak dieback – Center of France	
Forêt des Agreaux and Auberive	(O, E). Forest scale (1000ha) – Forests supporting academic training – Sustainable forest management - South-West and North-East of France	

APPENDIX 8 - TRAINING RELATING TO FORESTT CHALLENGE AREAS

1) State of initial and life-long training in France

Research training at PhD level is currently provided by all the French research institutions involved in FORESTT. Graduate schools are mostly discipline-based in local universities, but many encourage interdisciplinary training modules, and some are used to integrating forest issues. Master's degrees are currently awarded regionally (see section 2 below), by both graduate schools in engineering ('diplôme d'ingénieur des Grandes Ecoles', in particular AgroParisTech) and universities, with international partnerships (*e.g.* double degrees, exchanges of staff and students) and widespread use of the Erasmus program. Research institutes contribute to training through structured partnerships and strategies. French university programs at The master's degree and doctoral levels include large numbers of foreign students. Better use should be made of the network of CIRAD and IRD researchers working abroad, in partnership with universities in Africa, Asia or South America, in an international higher education and research strategy. Moreover, INRAE leadership in forest science should also be valorized to structure an internationally recognized French higher education strategy.

Regional initiatives are in place to promote the forest sector and enhance its training capacities at all levels (see here for Eastern France and here for South-Western France). Higher education programs are increasingly regionalized, with financial support for innovative training coming for "Programme Investissement d'Avenir PIA" initiatives. Several innovative master's degree programs have recently been established as double tracks or double degrees (see section 3 below), to foster research approaches to forest and bioeconomy management in forest and wood engineering, and to promote ecology in forest and wood engineering. Universities are developing new types of training by research that are more interdisciplinary and problem-oriented, as illustrated by the very innovative master's degree program in wood science in Montpellier, and the double-track economics/engineering course in Nancy to attract the best students in engineering to research in economics. The 'Forest and wood'

working group of the national Agreenium Alliance is responsible for national coordination and, after a few years of national prospecting and networking, it is now preparing a European COST action on the match between forest higher education and the role of forests in tomorrow's society with GIP ECOFOR. Life-long training is organized by many professional institutions as well as through higher education (*e.g.*, AgroParisTech specialised masters on "Forest, Nature, Society" and "International Management"). In a context of uncertainty and transition to climatic, forest ecosystem and socioeconomic situations that we have yet to experience, research expertise is being increasingly important. For instance, the ONF and CNPF are involved in technical training for the adaptation of forests to climate change based on the ClimEssences web tools developed within the RMT AFORCE. INRAE and IGN have developed training in remote sensing data analysis for ONF staff. Finally, FORESTT communities are used to interacting with citizens, from scientific mediation to ambitious citizen science projects (*e.g.* SURVIVORS or Tree Bodygards projects), in which citizens collect and analyze data, formulate research questions, debate results and, thus, improve our understanding of what science and socio-technical controversy are. The "Tous Chercheurs" platform of LABEX ARBRE also proposes a methodological framework for the design of citizen science projects.

2) Degrees in which forest and wood sciences predominate

Name	Profile	Organizing institution(s)	Where	Nb grad. /year
Engineer AgroParisTech – Tracks: Environmental Management of Ecosystems and Tropical Forests, Forestry Management, Engineering of Urban Vegetated Areas, Management of Natural Environments, Forest resources and wood sector	Forest management & forest sciences	AgroParisTech	Nancy, Montpellier, Paris	60
Master international STAAE « Gestion environnementale des écosystèmes et forêts tropicales »	Tropical forest management	AgroParisTech & Institut Agro	Montpellier	10
Master spécialisé « Forêt Nature société, management international »	Forest policy, economics and management	AgroParisTech collaboration with HEC Paris	Montpellier, Paris, Nancy, Kourou	12
Engineer in forestry and engineering sciences - Tracks : forest management, resources and forest-wood chain, environmental management of tropical forests.	Forest science and management	AgroParisTech	Nancy, Montpellier	30
Ingénieur Management forestier et logistique d'approvisionnement en bois	Forest science and management	BSA	Bordeaux	15
Ingénieur ENSTIB	Wood science and technology	ENSTIB (U. Lorraine)	Epinal	95
Ingénieur ESB	Wood science and technology	ESB	Nantes	95
Master AETPF Bois Forêt Développement durable	Forest resources and bioeconomy	U. Lorraine ENSTIB AgroParisTech	Nancy	20
Master AETPF Forests and their environment	Forest ecology and global change	U. Lorraine AgroParisTech	Nancy (DD with U. Valladolid and Freiburg)	12
Master AETPF Ecosystèmes agricoles et forestiers	From plants to landscape management	U. Lorraine AgroParisTech	Nancy	20
Master AETPF Forêts et Mobilisation des bois	Forest biology, management and harvesting	U. Orleans	Orleans	10
Master BEE Gestion Intégrée des Agrosystèmes et des Forêts	Forestry and agroecology	BSA and Université de Bordeaux	Bordeaux	15
Master BEE Biodiversité et Gestion des Écosystèmes Tropicaux	Ecology and social sciences, tropical biodiversity	AgroParisTech, U. Montpellier	Montpellier Kourou	15
Master Ecologie des Forêts Tropicales	Ecology, biodiversty, modelling , tropical forests	Kourou	Kourou	12
Master Sciences du Bois	Interdisciplinary wood sciences	Université de Montpellier	Montpellier	15
Master EMJMD European Foresty	Forest sci and eng at European level	AgroParisTech (6 european universities, coordinator UEF)	Nancy (Joensuu, Freiburg, Vienna, Brasov, Leida)	23
Master EMJMD SUTROFOR	Sustainable tropical forestry	AgroParisTech (5 european universities, coordinator U. Copenhagen)	Montpellier (Copenhagen, Dresden-Tharandt, Bangor, Padova)	20

3) Existing programs based on dual or multidisciplinary skills involving FORESTT communities

- Agricultural and forestry engineering + economics, social and management sciences: "Gestion Environnementale des Ecosystèmes et des Forêts Tropicales" option AgroParisTech
- Forest ecology and social sciences: Master's degree in AETPF Forests and their environment Nancy, BEE master's degree in the biodiversity and management of tropical ecosystems (*Biodiversité et Gestion des Écosystèmes Tropicaux*) at Montpellier
- Forest/wood engineering and advanced economics: Research-oriented master's degree in environmental economics organized as e-learning and evening classes, in addition to an "engineering" diploma.
- Forest ecosystem environmental management and social economics: joint venture between AgroParisTech and HEC Paris in a specialized master's degree course in international FNS

management.

- Forest ecology and management + wood sciences and technologies : Double-degree "engineer" ENSTIB + AgroParisTech Nancy, AETPF master's degree in wood, forests and sustainable development (*Bois Forêt Développement durable*) at Nancy
- Master of sciences in wood, Montpellier, multidisciplinary and project-based learning
- Master's degree in architecture, wood and construction (*Architecture, Bois, Construction*) and double-degree ENSTIB + *Ecole d'architecture de Nancy* : wood engineering for construction + architecture.

APPENDIX 9 – LIST OF CURRENT RESEARCH PROJECTS FUNDED BY THE EU OF RELEVANCE FOR FORESTT

Project	Funded by	Coordination	French partners	Links with FORESTT scientific challenges
MixForChange	ERANET BIODIVERSA	CIRAD	INRAE	**SC3**
FunPotential	ERANET BIODIVERSA	Finland	INRAE	**SC1 SC3**
MicroEco	BIODIVERSA+	Finland	INRAE	**SC3 SC4**
I-Maestro	ERANET FORESTVALUE	INRAE	INRAE	**SC3**
MULTIFOREVER	ERANET FORESTVALUE	FCBA	FCBA, INRAE	**SC3**
NOBEL	ERANET FORESTVALUE	Austria	INRAE	**SC1 SC2**
COSMYCA	ERC Consolidator grants	INRAE	INRAE	**SC3**
GLOBAL	ERC Consolidator grants	IRD	IRD	**SC3**
DOPAMICS	ERC Starting grants	IRD	IRD	**SC3**
Eco2Adapt	Horizon Europe	INRAE	IRD, ONF	**SC2 SC3**
OptForest	Horizon Europe	INRAE		**SC3**
EUFORE	Horizon Europe	EFI	INRAE, GIP ECOFOR	**SC1, SC2, SC3, SC4**
wildE	Horizon Europe	INRAE		**SC1 SC3**
PHENET	Horizon Europe (infras)	INRAE	CIRAD	**SC3 SC4**

BENCHMARKS	Horizon Europe (mission soils)	WUR	INRAE, APT, UL	**SC4**
FIRE-RES	H2020 Green Deal	Spain	INRAE	**SC1 SC3**
FIREURISK	H2020	Portugal	IRD	**SC1**
SUPERB	H2020 Green Deal	Finland	INRAE	**SC1 SC3**
HOMED	H2020-EU.3.2.1.1	INRAE	INRAE, ONF	**SC1 C3**
FORGENIUS	H2020-EU.3.2.1.1	INRAE	INRAE, ONF	**SC3**
RESONATE	H2020-EU.3.2.1.4	Finland	INRAE	**SC1 SC2 SC3**
UNRAVEL	H2020-EU.3.2.6.1	The Netherlands	CNRS	**SC2**
B4EST	H2020-EU.3.5.1.	INRAE	INRAE, CIRAD	**SC1 SC3**
eLTER PLUS	H2020-INFRAIA	Finland	CNRS	**SC1 SC3**
KOMODOH	MSCA - IF	INRAE	INRAE	**SC3**
ECO-MOUNTAIN	MSCA - IF	INRAE		**SC3**
RESET	MSCA - IF	CNRS		**SC1 SC3**
THrESholds	MSCA – IF	CNRS		**SC3**
Inspire4Nature	MSCA-ITN	CNRS		**SC1**
TreeMAAP	MSCA-IF	IRD		**SC3**

Trop De Trait	MSCA-IF	IRD		**SC3**
Fire-Adapt	MSCA-RISE	Spain	IRD, Sorbonne U.	**SC1, SC3**
IDEAS	UE-INPTA	CIRAD	CIRAD	**SC1 SC3**
RIOFAC	UE-INPTA	CIFOR	CIRAD	**SC4**
DIABE	UE-INPTA	ONG Planète Urgence	CIRAD	**SC2**
SWM	UE-INPTA	CIRAD		**SC3**

APPENDIX 10 – EXPECTED OUTCOMES OF FORESTT

Scientific Challenge #1

Management of forest trade-offs and synergies

-Global and local insights into trade-offs, synergies and conflicts in forest management strategies

-Decision support tools for managing trade-offs between forest ecosystem services at different spatial scales for orienting management and land-use strategies

Decision-making under uncertainty

-Multi-risk approaches relating to uncertainties concerning the short- and long-term orientation of forest management

-Private mechanisms and public tools for risk anticipation and crisis prevention

Support for forest innovations

-Recommendations for strategic environmental management approaches incorporating scientific advances

-Diagnosis of the French forest innovation system and proposals to improve its efficiency

Orchestrating the forest social-ecological transition

-Critical analysis of multi-levels, private and public forest policies and management systems

-Recommendations for a democratic forest social-ecological transition

Scientific Challenge #2

Current and future resource assessment

-Definition of relevant properties determining potential, according to wood use

-Basic knowledge of wood formation and the determinants of wood properties

-Characterization of the diversity of raw materials by sets of relevant properties

-Characterization of resource quality, including socioeconomic capacities of actors (based on demonstrators in living laboratories), including wood properties in forest resource models

Adapting processes and products to current and future resources

-Prototype innovative processes and wood products adapted to the diversity of forest resources

-Promotion of adjuvant-free products, decontamination, recyclability and upcyclability

-Producing data on products, processes & supply chains for sustainability assessment beyond LCA

Analyzing and modeling bioeconomic systems

-Models of the forest sector at global scale for policy-makers, including the wood-based bioeconomy and other forest ecosystem services

-Companion modeling and decision-making tools for national policy-makers and territorial stakeholders

-Shared view of the wood industry and forest ecosystem (existing and future opportunities)

Scientific Challenge #3

<table>
<tr><td colspan="2">Anticipating
-Re-examination of guidelines on forest reproductive material across regions for afforestation, reforestation and restoration
Simulating
-Models for predicting forest productivity, tree species survival and recovery after disturbances
-Simulators of forest growth and health adapted to new forest management practices and taking risk management into account
-Improvement of decision support systems to optimize trade-offs between forest adaptation and CC mitigation
Managing
-Adaptive forest management practices improving resilience and the provision of forest ecosystem services and products at the forest stand and landscape levels.
-Guidelines for crisis management</td></tr>
<tr><td><u>Planted forests</u>
-New improved varieties with greater resilience to biotic and abiotic perturbations
-Guiding species or provenance choice for afforestation, reforestation & restoration programs
-Recommendations for mixed-species plantations</td><td><u>Natural forests</u>
-Models predicting the adaptive capacities of natural populations to support forest resilience
-Molecular & phenotypic diagnostic tools to detect endangered genetic resources
-Conservation strategies to halt the genetic erosion of threatened populations</td></tr>
</table>

Scientific Challenge #4

Contributing monitoring systems and data for policy support: global stocktake of the Paris Agreement, European Forest Strategy, prioritization of protected forest areas

Supporting forest science research with long-term monitoring infrastructures

Providing prognostic models and data visualization platforms for forest managers in France (including overseas territories), and private owners for resource planning

Creating innovative monitoring assets: very high-resolution remote-sensing for forests; AI-based feature identification (trees, species), hyperspectral technology for forest health and biodiversity

Strengthening the international position of France in research on forest carbon and biodiversity

Reinforcing the role of French overseas territories as a research laboratory for forest research and a model territory for the tropics-based deployment of infrastructures