AGENCE NATIONALE DE LA RECHERCHE
ANR

Appendix to Work Programme 2018

Description of research associated with the ANR Generic Call for Proposals 2018 (extended version of section B of WP 2018)

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Contents[1]

[1] WP = Work Programme 2018 (reference to the paragraph in the main Work Programme 2018 document)

B.1 – Efficient resource management and adaptation to climate change: towards an understanding of global change.

Introduction

In light of world population growth and ever-increasing needs in terms of energy, raw materials, products and services, environmental changes are becoming an increasingly pressing matter at all scales, from individual landscapes to the planet as a whole (climate, biodiversity loss, soil degradation, air and water pollution, etc.). This new era, dubbed the Anthropocene epoch, has brought with it the need for an integrated approach to managing both the environments and the development trajectories of human societies in all their diversity.

It is therefore necessary to expand our basic knowledge about the processes behind the changes and comprehend their local and regional effects on resources, ecosystems, societies and human activities, especially those dependent on ecosystem services. There is also a need for research into social innovations – legal, economic, political and technological – to avoid or reduce the impacts, compensate for losses, restore environments and adapt to new constraints and opportunities. This challenge contributes to major international initiatives in the field (GEO, Future Earth, GFCS, IPCC, IPBES, SDG, etc.) and is backed by Belmont Forum international calls for proposals. All this research is firmly rooted in the context of the Paris climate agreement signed at COP21 in late 2015, the first ever universal climate agreement. Awareness of the threats to human well-being and the need to develop procedures for implementing the Paris Agreement raise new research questions under the two themes described below and themes shared with other challenges (see section B.11).

B.1 – Theme 1: Fundamental knowledge about natural environments and biodiversity

B.1 – Theme 1 – Subtheme 1.1: Fluid and solid earth.

Functioning and evolution of climate, oceans and major cycles

Climate affects all compartments of the Earth system: the atmosphere, oceans, cryosphere and the continental surfaces that interact closely with the biosphere and human societies. The challenges are to (i) better understand and represent the processes, identify and reduce bias and uncertainty in models (gas-aerosols-clouds, ocean circulation, ocean-atmosphere coupling, marine biogeochemistry, dissipative flows and mechanisms, non-linear or chaotic phenomena, nesting of scales and spaces, teleconnections, interfaces between environments, large water, carbon, nitrogen and phosphorus cycles etc.); (ii) understand the mechanisms underlying climate sensitivity, and in particular to identify tipping points; (iii) better understand the uncertainty surrounding the sensitivity of the natural system and aim to reduce it by using observation data; (iv) predict climate change at regional level and quantify its impacts for a wide range of potential increases in global average temperatures (from 1.5°C to 4°C by 2100). The system's behaviour in phases of negative greenhouse gas emissions must also be studied.

The subtheme encourages studies of energy, matter and pollutant transfer processes

along coastlines and in coastal areas and their interfaces with offshore oceans, continental areas and the atmosphere in order to remove the barriers to our ability to model these aspects of the Earth-Sea continuum and their current and future responses to pressures from human activity.

Global warming, which is chaotic and marked by extreme events, leads to questions about natural variability and the distinction between natural and anthropogenic signs. On this last point, it would be useful to develop studies in terms of the Earth's energy budget, currently out of balance, which is a relevant and effective indicator of the state of climate change and interactions between sub-systems (by developing and building on integrated observation networks and on modelling interactions, including in the most recent millennia or ancient periods). Capitalising on large global re-analyses of the Earth system from the last decades or centuries is encouraged for a better understanding of modes of regional variability, associated extremes and their predictability.

Scales ranging from season to decade are crucial to decisions on adaptation. At the same time, research on spatial downscaling in connection with climate projections is expected in order to describe more accurately the evolution of high-impact phenomena, address the problem of urban climate and account better for the heterogeneity of surface states and land use in drawing up proposals for adaptation. Studies are also encouraged on methods of climate change detection/attribution, including the occurrence of extreme past, present and future events; examining the effects of differentiated anthropogenic forcings (greenhouse gas emissions, aerosols, land uses etc.) also remains a challenge to be addressed.

Characterisation, dynamics and functioning of the critical zone and the associated biosphere

The critical zone stretches from the lower atmosphere to aquifers and comprises a series of interdependent ecosystems made up of crucial resources: air, the visible and invisible biosphere, soil, surface water and groundwater. It is responsible for the many functions of these ecosystems: transfers of biotic and abiotic matter, biogeochemical cycles (C-N-P etc.) and numerous services: climate regulation (including greenhouse gases and carbon sequestration), supplies (food, fibres, wood etc.) and the preservation and renewal of resources (water, soil fertility and protection, biodiversity related to soil and water, etc.).

Research is expected on (i) biotic and abiotic interactions and retroactions between soil, water, air, vegetation, other living organisms and human activities, (ii) the coupling of biogeochemical cycles of major, minor, trace and contaminant elements, (iii) the transfer of energy and matter (solid transport, in suspension or in solution) and (iv) the formation and/or evolution of components of the critical zone (soils, aquifers, drainage basins etc.), the role of interfaces (ecotones, hyporheic zones, wetlands, coastal areas etc.).

Special attention should be paid to questions of the transfer of spatial scales (connectivity, emergent properties etc.) and temporal scales (time constants, threshold effects, scenario-building, etc.). With this in mind, the development of new approaches, methods and technologies is encouraged to better identify and take account of variability in the properties and functions of the various components of the critical zone.

Understanding the state and dynamics of hydrosystems and continental aquatic ecosystems and the ecodynamics of substances must contribute to reducing hazards

(floods, low water, droughts) and risks (loss of good physical, chemical and/or ecological condition). It is important here to define clearly what good condition is and how it is measured, which implies moving from static indicators to functional and dynamic indicators.

By better defining the response times and resilience of the critical zone's components when subjected to disturbances, the issue is to identify, quantify, analyse and model the zone's response to the multiple pressures of global change, be they linked to climate change, changes in land use and/or other human activities, through a systemic, interdisciplinary approach drawing on long-term methods of observation and experimentation.

Knowledge of mineral resources: deposits and environmental impacts

Mineral resources remain crucial for industrial activity and the development of new technologies, particularly those relating to electronics and digital applications, transport and renewable energy (energy resources are covered by the "Clean, safe and efficient energy" challenge).

Even if universally adopted and optimised, recycling will not be enough to cover growing needs. The exploitation of known deposits has to be optimised, but new deposits of raw materials and especially crucial metals must be found. New knowledge is needed about terrestrial and marine deposits in their geological and environmental context. Mining deposits and operations have an impact on the natural environment and biodiversity, on resources and on human populations. Assessing these impacts in the short and long term remains a major challenge. It is also important to develop operating strategies that can reduce these impacts significantly and rebuild sustainable ecosystems once operation has ended. New approaches are needed for the observation, comprehension and integrated modelling of the processes in play in the mining environment during exploration, operation and/or post-mining phases.

New research, methods and technologies must be developed to shed light on the processes governing the creation of deposits and mineralisations. From exploration to the extraction of useful substances, knowledge is needed about the spatial and temporal dynamics of deposits, from the transfer of complex ore-forming fluids to structures favouring accumulations and their successive deformations. These pathways are essential in locating resources, assessing their potential, identifying the impacts on natural environments (soil, water etc.) early on and better understanding and modelling the long-term environmental impacts (mine and post-mine monitoring). B.1 – Theme 1 – Subtheme 1.2: Living earth.

Exploring biodiversity and analysing the ecology, evolution and dynamics of species, populations and communities

More intense investigation is needed of the lesser-known branches of biodiversity, especially those found in environments with little or no human impact, analysing the mechanisms that explain the origin, maintenance and evolution of biological diversity in all its dimensions – genetic, phenotypic and functional – using the conceptual framework provided by evolutionary biology and scientific ecology.

Research is expected to develop knowledge about biological diversity, systematics, the evolutionary history of organisms, especially in regions and ecosystems that are rich in biodiversity, including soils, and mechanisms as well as the interactions between the

ecological and evolutionary dynamics underlying the processes of genome, species and population divergence and convergence.

The expected research also covers the dynamics of species, populations and groups of species in their ecosystem and the evolution of personalities and behaviours in interaction with the environment and human activity. Particular attention should be paid to better understanding the vulnerability and responses of organisms to the various pressures of global change: long-term monitoring of populations or species in relation to the environment and human activity, the role of associations between macro- and micro-organisms, animals and plants in the functioning of ecosystems and their resilience (taking the microbiota and the concept of holobionts into account), the ability of organisms to respond to changes in their environment at the infra-specific scale, the long-term dynamics of communities, populations and species, including ancient periods if they can assist in understanding the current changes in the environment, and the ability of an ecological system to adapt or evolve according to taxonomic and phylogenetic diversity.

NB: Although the analysis context is ecosystemic, the research is limited to ecosystems with no human impact. A cross-disciplinary theme is devoted to the dynamics of production ecosystems.

B.1 – Theme 2: Scientific and technological innovations to support the ecological transition

This theme addresses the challenges of identifying and mitigating the causes and/or adapting to environmental changes and their impacts, as well as corrective (remediation) or preventive approaches involving reducing the associated risks (the circular economy, associated with new industrial sectors, comes under the "Stimulate industrial renewal" challenge or the bio-economy theme.) To avoid, reduce or offset environmental risks, research should take into account the existing levels of uncertainty in our knowledge of the environment and ecosystems. Public-private partnerships focusing on the following priorities are preferred in this theme.

Development of sensors for environmental monitoring (smart monitoring)

The heterogeneous nature of the environment limits the scope of conventional metrology and the effectiveness of many preventive and protective solutions. New generations of sensors or detectors are needed to for observation and diagnostics systems.

Technological, digital, economic and methodological breakthroughs are expected, incorporating cost reductions, miniaturisation, the autonomy, sensitivity, reliability and robustness of sensors in actual situations, increased data flows and in situ and/or continuous measurement, especially with regard to complex matrices and cocktails of biological contaminants or pollutants and invasive species.

Technology transfer is expected through information and communication science and technology, the life sciences and geoscience. All environments are covered – water, sea, coast, air, soil, forest – including their biotic and abiotic components, with application to natural or human-influenced environments.

Methods and tools for operational alert and environmental crisis services

In the field of forecasting, preventing and managing environmental alerts or crises, a

synergy or "cascade" effect of natural and/or human-induced risks is frequently seen[2].

Methods and tools are expected for the operational services dedicated to these multiple risks, for all environments, incorporating modelling, assimilation and data visualisation tools. These advances should make it possible to manage large amounts of data from multiple sources in real time or almost real time and to incorporate it into predictive models. The ultimate aim is to assess impacts better and identify the mechanisms and conditions under which alerts are raised in order to make risk and crisis management more effective.

Proposals are encouraged for integrated forecasting systems that can produce data and scenarios based on the possible causes of a crisis or disaster or a series of pressures occurring in sequence or simultaneously. Several different alert systems can be combined in consultation with the stakeholders and users involved.

Methods and technologies for sustainable remediation, ecological engineering and climate engineering

The priority in terms of remediation is to restore the quality of soils, sediments, biodiversity, water and the services they provide and to develop climate engineering. This means advancing the concept of "curative treatment" towards more systemic concepts of sustainable remediation, such as self-repairing ecosystems, and instigating integrated strategies to deal with primary needs whilst meeting societal needs. Proposed solutions must include a methodological core based on tools such as life-cycle analysis or other forms of cost-benefit analysis. The introduction of technology packages will be centred around the ability of materials or products to be recycled.

For polluted sites and soils, new processes or treatment combinations are expected (pedogenetic engineering, soil reconstruction, etc.).

In terms of water, disruptive projects will be preferred, incorporating i) consideration of emerging pollutants and their metabolites, ii) effluent recovery (phosphorous, nitrogen, metals etc.) and iii) increased energy production.

In the marine environment, the programme should help to i) develop new design and eco-design strategies for marine construction and infrastructure and ii) conduct ecological restoration experiments at different pilot sites (including sensitive and intertropical environments).

The priorities for ecological engineering will be based on solutions inspired by nature and maintaining ecosystems in good ecological condition. Preference will be given to protocols for solution monitoring and integration into existing sectors.

In terms of climate, the programme aims to develop French expertise in climate engineering, including i) the management of solar radiation and its impacts and ii) the capture of atmospheric CO2 or CO2 sequestration in the oceans. For all the techniques envisaged, environmental, ethical and political reflection is expected about the associated risks and the governance of the solutions being considered.

[2] Chronic and accidental pollution with toxic or allergenic products, eutrophication, species invasions, biodiversity erosion, flooding and high water levels, coastal erosion, land movement, eruptions, earthquakes, storms, fires, droughts, natural or man-made low water levels, overuse of water etc.

Reducing and controlling the environmental impact of new economic sectors

The new economic sectors associated with the ecological transition (industries, energy, agriculture and mining, including storage) must commit to environmentally-friendly exploitation of natural resources and have little or even a positive environmental impact whilst maximising the socioeconomic benefits. Specific research should be carried out in the context of the development of these new sectors to analyse, minimise and prevent the potential impact and the environmental and socioeconomic risks, making specific recommendations for each economic sector. There is a need, for example, to develop bio- and geo-inspired processes (for the production of raw materials, energy or materials, for the treatment or storage of carbon, energy etc.), to assess regional synergies in order to make more efficient use of resources (water, energy, raw materials, soils) using the tools of industrial ecology, to prepare scenarios describing the potential pressures and impacts of these new sectors on the environment and on health, to facilitate the digitisation of these sectors, to anticipate and identify key issues in monitoring the impacts of these sectors and to monitor both benefits and risks at the level of a sector or a region.

B.2 – Research to be conducted in response to the "Clean, safe and efficient energy" challenge

Introduction

ANR aims to use this challenge to mobilise the best scientific and technological skills to tackle the issues of the energy transition at both national and global level and to help construct the future energy mix in the context of France's "Factor 4" emissions target for 2050. It contributes to the SNR in this area, to the recent National Energy Research Strategy (SNRE) introduced in an Order of 21 December 2016 by the Ministers for Energy and Research, and to France's commitment to doubling public R&D funding for clean energy announced during COP21 at the end of 2015 (see the Mission Innovation[3] site).

The challenge focuses on six major objectives:

- Promoting the **systemic**, **integrative** and usually **multidisciplinary** approaches often required when dealing with energy issues; although the social sciences and humanities have a specific subtheme (subtheme 1.7), their capacity for interdisciplinary research favours their deployment with regard to the other, more technological, subthemes within the challenge;
- Mobilising all scientific disciplines (physical sciences, engineering sciences, Earth sciences, life sciences, mathematics, information and communication sciences, social sciences and humanities) capable of producing **basic knowledge** relevant to the energy transition; preliminary research may be aligned with subtheme 1.1, but must also correspond to the thematic issues laid out in the other subthemes;
- Promoting and **exploring** radically new ideas and **disruptive concepts** outside existing paradigms (see subtheme 1.1);
- Designing **materials, methods and processes** for use in energy technologies; the intention is to support a wide spectrum of projects on **energy-related materials**, ranging from research and design focusing on materials with the properties required for the target applications to their integration into functional systems;
- Providing **proofs of technological concepts**, which may include developing new laboratory test facilities or integrating facilities into existing experimental sites. However, the scope of this challenge is limited to the earlier stages of development (Technology Readiness Levels 1 to 5), complementing other R&D funding schemes targeting later phases at both national level (ADEME, BPI France etc.) and European level (Horizon 2020). However, project coordinators – even for preliminary research – are encouraged to reflect on application conditions and constraints, lifespan, costs, reduced reliance on rare or toxic raw materials or searching for substitutes etc.;
- Promoting the contribution of the **humanities and social sciences** to discussions on the energy transition and characterising the way in which societal choices are made through the deployment of energy technologies. Social sciences and humanities, through the plurality of their concepts and methods, are

[3] http://www.mission-innovation.net/participating-countries/france/

required to go beyond a sector-specific approach to technologies and to address the systemic dimension of innovations and their impacts.

Apart from the first subtheme, which is concerned with the production of basic knowledge and disruptive concepts, and subtheme 7, which aggregates contributions from the humanities and social sciences, the remaining subthemes cover energy issues from primary resource capture to end use, particularly in the industrial sector, including conversion of energy vectors, storage and distribution. Each subtheme includes research aiming to acquire basic knowledge about the theme in question.

B.2 – Theme 1 – Subtheme 1.1: Basic and exploratory research and disruptive concepts

Focused on producing basic knowledge and exploring disruptive concepts, this subtheme also aims to attract new communities towards energy issues and foster new partnerships. It cuts across the other subthemes in the "Clean, safe and efficient energy" challenge.

Core knowledge and basic research relevant to energy

Solving long-term energy issues requires a **foundation of basic knowledge** and consolidated scientific expertise in the physical sciences (physics, chemistry, etc.), engineering sciences (mechanical, thermal, process, etc.), Earth sciences, life sciences, mathematics and information and communication sciences (modelling, simulation, algorithms, control, automation etc.) and the social sciences and humanities. This subtheme aims to support **preliminary research guided by medium- to long-term applications in the field of energy** that could constitute the foundations of future technology.

Interdisciplinary research is naturally encouraged, given the complex nature of the problems falling within this challenge.

Disruptive concepts and proofs of concept

This subtheme aims to invite projects to explore **radically new ideas and approaches and disruptive concepts** relative to more incremental, scientifically accepted research. These breakthroughs can be part of the development of previously identified areas or seek to create new fields of research. Proposals must demonstrate how they stand out from more clearly signposted concepts.

B.2 – Theme 1 – Subtheme 1.2: Renewable energy capture and harvesting energy from the environment

In line with the SNR conclusions, researchers' attention is drawn to the need to lower costs and increase the conversion efficiency of energy generated from renewable resources, which will facilitate the development of renewable energy and increase its penetration rate in the energy mix, and to reduce or eliminate the use of strategic materials (rare earths, platinum etc.) for these technologies.

Solar resources

Given the abundance of solar energy, many ways of harvesting and using this energy need to be developed:

- Direct electricity generation via photovoltaic technology (based on inorganic,

organic or hybrid semiconductors, potentially combined in multi-junction cells, solar concentration and very high yield concepts). Module manufacturing technologies are also targeted;

- Heat production at low (**solar thermal**) or high (**concentrated thermodynamic solar**) temperatures for direct heating or for producing cold, electricity or hydrogen;
- Production of **solar fuels** by **photoelectrolysis**, potentially combined with **photocatalytic CO_2** conversion to produce synthetic hydrocarbons; the exploration of biomimetic or bioinspired pathways will be welcome.

Other renewable sources (air, water) and harvesting energy from the environment

Natural environments and certain human activities offer other energy resources such as waste heat that could be used to diversify and supplement the energy mix or produce energy for targeted applications. Other examples include air, hydraulic and heat flows, thermal and pressure gradients, vibrations, organic waste etc. Although a few technologies have already reached demonstration stage, harvesting these resources still requires research to pave the way for innovative, economically viable technologies over the medium and long term, both for renewable energy sources (**wind, hydraulic, marine energy**) and for the recovery (energy harvesting) and use of diffuse energies (**biofuel cells, thermoelectricity, piezoelectricity etc.**).

B.2 – Theme 1 – Subtheme 1.3: Energy from under the ground

Even though it produces a significant part of our energy resources, the subsurface remains a little known and under-explored environment. Rational, optimised and sustainable use of underground resources will help in achieving some of the objectives of the French energy transition act (LTECV) of 18 August 2015. Research is needed on both the extraction of key energy resources and the exploitation of underground storage capacity. The research should target the acquisition of knowledge and the development of tools, methods (multi-scale modelling in particular) and technologies for using the subsurface and exploiting its resources that are competitive, have a low environmental impact and can find a place in the future energy mix.

This research must mobilise the various aspects of the Earth sciences (geology, geochemistry, geomechanics, geothermal energy etc.) and other disciplines (including digital technologies). Progress is expected in the geological context and in geological characterisation, technical feasibility, energy yield and its preservation in the long term, which will require research into site monitoring and environmental risk management (monitoring strategies etc.).

This work may involve strengthening or developing new sectors, such as:

- **Geothermal energy** for the production of heat, cold or electricity, extended to broader geographical areas (diversifying the sources exploited) and its role in thermal storage processes;
- **Underground storage of CO_2**;
- Underground energy storage: **heat storage, CAES, hydrogen storage and new underground storage concepts;**
- The exploitation of **naturally occurring hydrogen**.

It may also aim to make mature sectors more environmentally-friendly:

- A safer **nuclear** sector, by increasing the safety of radioactive waste storage;

- "Responsible" exploitation of **hydrocarbons** (efficient energy and resource consumption and reduced impact from emissions);

The development of a **cross-disciplinary core of knowledge** and methodologies for exploring and evaluating the characteristics and potential of the subsurface for energy resource storage or extraction will benefit all sectors.

B.2 – Theme 1 – Subtheme 1.4: Conversion of primary resources into fuels and platform molecules, carbon chemistry

Whether they are biosourced or not, hydrocarbons will continue to play a major role in the future energy mix, if only as a long-term, high-energy-density storage method. Reducing the CO_2 emissions generated by the production, conversion and use of these resources is a major challenge.

Bioenergy

Research is expected under this challenge on the **production of bioresources**primarily for energy applications and the different **conversion processes** (biological, thermal, physico-chemical, hybrid processes etc.) for turning bioresources into **energy vectors**. These themes are described in more detail and placed into the wider context of the development of the bioeconomy and the varied uses of biomass, which is covered by a joint theme associated with the *"Clean, safe and efficient energy", "Stimulate industrial renewal" and "Food security and the demographic challenge"* challenges, to which this "bioenergies" subtheme is attached.

Recovering CO_2

The different methods of **transforming CO_2, especially captured fossil CO_2**, for **hydrocarbon production,** including using it to store energy from intermittent sources and/or to supply carbon molecules for chemical applications, should also be explored and developed.

Research into the production of **synthetic hydrocarbons** is particularly encouraged, especially for sectors with no current alternatives to oil (aeronautics, for example).

B.2 – Theme 1 – Subtheme 1.5: Dynamic management of energy systems: storage, networks, vectors

A large proportion of renewable energy sources are intermittent and their production is decentralised. This makes it important to ensure that transport and distribution networks operate **under optimum conditions and to provide energy storage solutions** capable of offsetting the gap between supply and demand. In addition, the development of on-board storage systems should reduce the dependency of transport systems on fossil fuels.

Hydrogen and fuel cells

Hydrogen has potential as a mass energy storage solution. However, it must be produced with minimal atmospheric emissions of fossil CO_2 (by **electrolysis** or **water thermolysis**, for example). At the same time, research is still required to develop **fuel cells and hydrogen storage solutions**, including research on materials and structures suitable for solid storage.

Energy storage

Although some types of storage are already mature, others have room for major progress or even require further basic research before becoming viable solutions:

- Storage in **electrochemical accumulators**, for stationary storage as well as on-board and mobile storage solutions, must be improved in terms of energy density and specific power as well as reliability, safety and environmental performance, whilst also reducing costs; **supercapacitor** storage also requires research to improve energy density and safety;
- Other types of **storage** required for **mass electricity or heat storage**;
- **New concepts for energy storage and management**, associated with **self-generation**, **self-consumption** and partial disconnection from the grid or the addition of new functionalities to existing systems (for example electric vehicle batteries, domestic hot water tanks), may be explored;

Transport, distribution, management and self-consumption of energy

It is important to work on elements enabling grid integration and electricity management for both stationary and on-board systems: **electrical engineering, power electronics, electrical machinery** (actuators and generators), which all rely on very high-performance materials (magnetic, dielectric and electromagnetic materials etc.) in order to be efficient.

The development of more widely spread, intermittent energy sources and storage facilities calls for research into **smart grid** concepts at different spatial scales to provide real-time optimisation of the energy system. Research drawing mainly on information and communication sciences is expected on:

- Network management, including the spatio-temporal prediction of renewable energy generation potential and power demand; in this perspective, the development of microgrids and local consumption (including self-consumption) and the design of flexible uses (mainly for industrial processes), load-shedding and demand side management should be considered.
- The load management dynamics of nuclear power stations, to compensate as far as possible for the intermittent supply of solar and wind energy and restrict the need to store electricity;
- Network security (resilience and reliability) and safety by design;
- Interoperability of energy networks (electricity, different gases, heat etc.).

B.2 – Theme 1 – Subtheme 1.6: Energy-saving industrial facilities and processes, capturing CO_2

Substantial energy savings and more efficient energy use may be achieved through direct efforts targeting **specific processes within manufacturing industries** (reduction in energy requirements for existing production processes and research into alternative processes that are more energy-efficient or have lower CO_2 emissions) and **energy generation** (improvements in conversion efficiency, loss reduction and energy recovery).

Auxiliary equipment and systems (pumps, hot or cold production systems, ventilation etc.) should also come under scrutiny. Research should take account of environmental constraints (extreme conditions, mechanical constraints, fouling and corrosion) and operational constraints (reliability, robustness, ease of use, return on investment etc.).

One key issue in energy efficiency is the development of methods and processes for heat recovery, transportation and reuse, including **waste heat**, either using **thermodynamic systems** (heat exchangers, heat pumps, the organic Rankine cycle etc.) or **systems involving materials** (PCM, heat absorbers etc.).

In addition to the search for greater energy efficiency, energy decarbonisation will depend on a higher proportion of low-carbon electricity in industrial processes (for example, induction or microwave heating) and on the development and optimisation of **combustion** processes with lower greenhouse gas emissions, including incorporating **CO_2** capture.

B.2 – Theme 1 – Subtheme 1.7: Energy transition and humanities and social sciences

In addition to the needs for primarily technical development outlined in the themes above, questions also arise in the social sciences and humanities. Developments expected in energy technologies are inseparable from the political, societal and environmental challenges. The diverse concepts and methods encompassed by the social sciences and humanities (development, anthropology, law, economics, geography, psychology, sociology, political science, town planning etc.) offer strong potential for disciplinary and interdisciplinary analyses of these issues and their links with technologies at the different stages in the innovation process. By addressing technology as an open, shifting assembly of social and technical entities, they can help in understanding the systemic nature of energy transition processes, the changing actions of stakeholders and the constant need to agree on what takes "priority" and what creates "value". The themes proposed below are not associated with a single discipline, but they encourage submissions of original, interdisciplinary proposals.

Territories in the energy transition

The emergence of climate and energy policies that are more systemic and open to local initiatives causes the question of territories to shift. Several themes need attention: the effect (leverage or obstacle) of different **social and geographical legacies** on pathways to transition, the governance of new energy systems at multiple levels and the redefinition of the **energy policy field**, the process of **building new regional energy resources** and the redistribution and attraction effects they can generate. These issues suggest **international research opportunities** in and outside Europe. In France, these territorial dynamics could usefully be considered in relation to the components of the energy transition act.

Energy demands and uses

Energy reduction and efficiency policies are powerful levers for the energy transition. Nevertheless, shifts in consumer **behaviours** and lifestyles are not easy to control. Beyond sometimes normative notions, demand must be understood as resulting from systemic processes in which **social, cultural, political and even historical dimensions** are intertwined in the routine but constantly renewed enactment of energy uses. In particular, this means analysis of the link between **social habits** and **energy access and management systems**; the construction of demand and its transformations (demographic and societal trends, the emergence of the consumer-producer-citizen, energy saving practices etc.); the role of **economic and non-economic instruments** and their use through public action (incentives, including non-financial "nudge"

incentives, quotas, ecotaxes etc.).

Energy transition, markets, regulation and governance

Governance of the transition is caught in the cross-fire between sector-specific legacies, climate negotiations, geopolitical renewals, market liberalisation, increasing numbers of stakeholders etc. Analysis could relate to the processes and choices involved in preparing and evaluating instruments (tariffs, tradeable allowances, bonuses, auctions etc.), cost dynamics, market and network design, sector models (economic, organisational, vulnerabilities and resilience), issues of the integration (equity, energy security) of new forms of energy (intermittent supply, flexibility, storage), new forms of energy access (distributed production, smart grids, solidarity between territories) or offers (differentiated kWh, etc.). All these options must be evaluated, along with their associated social, economic, industrial and environmental issues.

Future-building, forecasting, modelling

Quantified **scenarios**, backed by **forecasting models**, are increasingly used in energy policymaking. As contributors to these models, the social sciences and humanities have the task of **accounting better for the actual situation** (e.g. behaviours, technologies, innovation, technological or financial inertia etc.) in order to **shed light on diverse issues** (e.g. energy security, social impacts, objectives/resources of the French energy transition act etc.). They are also called on to provide perspective on the use of **models and scenarios** as **methods of constructing futures**. Research must therefore analyse these models, the **social worlds** that sponsor them and the **practices** associated with them (production, validation, circulation, role and influence in political processes etc.).

B.3 – Research to be conducted in response to the "Stimulate industrial renewal" challenge

Introduction

The image of French industry is tarnished by pollution generated within companies or in the environment. In addition, competitiveness is falling and products are ageing in sectors that have not opted to specialise in innovative, high-added-value products. French industry must therefore reinvent itself and strive towards clean, sustainable manufacturing, promoting a circular economy to get ahead of its competitors. This applies both to existing industries, which must be supported in their (r)evolution, and to **industrial sectors that need to emerge** to cater for new requirements.

The goal of this challenge is thus to support this transition, funding projects that prepare for these changes **in the medium and long term**. The research will cover broad **industrial fields** (e.g. manufacturing industries, chemical and process industries, agri-food industries etc.) and a huge spectrum of **scientific disciplines** (industrial engineering, robotics, ergonomics, human/machine interfaces, economics, physics, chemistry, mechanics, materials, process engineering etc.) that can deal with the **technological aspects** and associated **human and societal dimensions** (workplace organisation, integration in the urban fabric, valuing human capital, new business activities etc.). The research will target all aspects of current or emerging industries, from the design, manufacture and assembly of materials and objects to industrial organisation and the world of work. However, projects relating to materials developed primarily for the energy sector should be submitted under the "Clean, safe and efficient energy" challenge.

The results of this research are expected to provide **medium- or long-term renewal**, which will combine **innovation, savings and solutions to society's pressing needs**. Thus, in line with the "industrial leadership" priority and the "key enabling technologies" (KET) aspect of the Horizon 2020 programme, the "Stimulate industrial renewal" challenge aims to support studies at a broad spectrum of TRL (TRL 1 to 4), ranging from basic research with no immediate applications to research guided by industrial issues. Consequently, **the various themes will also consider basic research projects focusing on new approaches.**

The renewal of French industry involves **multiplying the links between academic laboratories and business**. These links may include technology transfer, but they should also enable **a rapid transfer of newly-acquired knowledge to potential users**. Proposals may therefore be experimental, theoretical, technological, industrial or instrumental, and may include fundamental aspects of knowledge acquisition. Proposals are expected to be evenly spread between breakthroughs away from existing approaches, the elimination of technological barriers in new production processes and the acquisition of new knowledge on themes of interest. Modelling and simulation may be included in proposals meeting the above objectives or be the focus of specific proposals.

B.3 – Theme 1: The factory of the future: people, organisation, technologies

Faced with demand for more personalised products, the factory of the future will create a flexible, interactive relationship with its suppliers and subcontractors. It will design high-quality, competitive products and services. It will be safe and integrated into its

local ecosystem. **Supporting and enhancing the development of new digital or manufacturing technologies** is a prime area for potential breakthroughs: development times must be cut to meet the demand for personalised, optimised products. **Promoting a systemic vision and organisation of the factory** emerges as a second disruptive theme: there is a clear need for an agile development process that includes the life cycle and value chain dimensions and where the customer and suppliers interact with the industrial system**. People-focused factories** is the third disruptive theme: workplace organisation becomes more flexible, but people remain at the centre of operations. As possibilities for regulation may diminish, a solid understanding of human work processes will be necessary to address production challenges whilst reducing the cognitive and physical workload. Proposals may draw from different scientific communities: engineering sciences, information science and technology, social sciences and humanities. Cross-disciplinary proposals taking technological and human aspects into account are encouraged, as they are likely to provide the significant breakthroughs required to design the factory of the future.

People in new productive organisations

The modern manufacturing system will be based on an optimal distribution of tasks between humans and machines, as well as on more continuous adaptation of labour to workers' physical, sensory and cognitive capacities. An increasing number of questions will arise: how do we provide methods for individual and collective regulation of activity? How can health and safety be integrated into the logic of production? How can we help the people at the heart of the factory who are directing and deciding to deal with abnormal and unexpected situations? New ways of organising work are emerging (e.g. networked companies), creating opportunities and risks which must be explored.

Smart, connected, controlled factories

With the Internet of Things, the product carries within it the data needed for supplies of its components and the traceability of its production. Access to production data makes it possible to adapt manufacturing in real time. Compiling, analysing and disseminating the information gathered makes troubleshooting and decision-making easier for operators and management. The interconnection of systems between the factory, its suppliers and customers shortens manufacturing time, reduces stocks and contributes to the agility of the industrial system. Lastly, the factory is a distributed, interconnected cyber-physical system that incorporates cybersecurity from the design phase.

Virtual factory

Advanced solutions for human-machine interaction, virtual reality, augmented reality, product-process design and optimisation and collaboration simulation will validate new operating scenarios. Virtualisation should also support the activities of engineering, production and maintenance teams through business information systems and create tools to meet training and knowledge management requirements. The multiple uses of augmented reality are capable of transforming the nature of work and it will be important to anticipate their effects, especially on physical and cognitive workload and the regulation of activity.

Flexible, agile factory

Companies must supply renewed, personalised, complex products for mass or niche

markets. It must be possible to reconfigure the production system by reusing resources that can be personalised on site, using plug-and-play and system engineering approaches. Agility is important from the operational process and product design phase. Proposals must rethink the place of people, taking into account the interactions between the engineering, production and maintenance teams and the development of skills.

Green factory

All this is an incentive to design more sustainable production systems. Innovation must be increased throughout the supply chain to achieve processes that consume less energy and raw materials. The creation of industrial ecosystems must be encouraged to optimise energy generation and consumption and the consumption and flows of materials. To reduce the environmental footprint, ecodesign is essential when the product or service is being designed and at all stages in its life cycle, from design to recycling.

Industrial robotics and multi-robot cooperative systems

The programming of manufacturing robots could be based on advanced learning, artificial intelligence and control techniques. The study of coordinated fleets of robots in factories is relevant, together with collaborative robotics, with robots providing precision, endurance and effort while humans contribute judgement and decision-making. Natural, efficient and safe collaboration between operators and robots will mobilise new methodologies and technologies (e.g. sensors and actuation) to increase the sensitivity and dexterity of the robot and improve both verbal and non-verbal communication. Collaborative robots also are capable of learning, so that operators can fashion them for their own use.

New production and control technologies

Innovative technologies for production, assembly, control and measurement will provide high added value for customised products. Additive manufacturing improves objects' strength, weight and environmental impact, but it still faces considerable scientific challenges and improving overall equipment effectiveness remains a major challenge. For quality assurance, monitoring based on multiple measurements creates problems in processing large volumes of data and extracting useful knowledge to take corrective action or assist operators.

B.3 – Theme 2: Metallic and inorganic materials and associated processes

Metallic or ionocovalent materials (metals and alloys, ceramics and glass, hybrids, natural materials etc.) and their interfaces and surfaces are strategic elements in industrial renewal and business competitiveness, especially for aspects related to resources, performance and new functionalities. They are inseparable from the pathways used to obtain them (preparation, shaping, assembly etc.), and efforts are being made to make them more efficient, environmentally friendly and compatible with regulations. This approach also applies to recycling. Preparation processes, simulations and thermodynamic studies are major issues. The development of materials for use in extreme conditions (very high temperatures, severe mechanical stresses, high strain rates, highly corrosive environments, irradiation etc.) is also encouraged.

Functional inorganic materials

Inorganic materials (including ceramics and glass) have many applications in our day-to-day lives, for example in electronics, information storage, energy conversion and storage etc. Efforts to seek new materials with functional (electrical, magnetic, thermal etc.) or multi-functional properties must continue. Proposals should seek to develop new structures and new functionalities to replace sensitive elements (scarcity, chemical risk, costs etc.). Modelling or simulation of a material's properties in relation to its structure or composition will be encouraged in order to improve understanding and control.

Metallurgical science and engineering

Every change or disruptive innovation in the design or use of metallic materials has an impact on many industrial sectors: aeronautical, automotive, railways, construction, packaging industries etc. Proposals will focus on developing innovative alloys and may promote the use of recycled components. They will be structured around an approach based on the relationship between microstructure and properties, and may involve the use of simulations (*ab initio* calculation methods, thermodynamic and kinetic coupling, simulating the origins of microstructures). These approaches, strongly coupled with experimentation operating at the same scales as the simulations, become powerful tools for shortening development times and replacing conventional empirical approaches.

Surface and interface: functionalisation, surface treatment

Solid materials generally have a primary function, which may be structural for example, but they interact with the environment via their surface and any coatings. Surface treatments and thin film coatings confer new characteristics or functionalities in relation to their environment. The techniques used are varied and may also be combined. Innovative approaches must be developed in this area, in terms of both the proposed process and the properties sought.

Assemblies

Assembly processes (bonding, riveting, welding, brazing etc.) are widely used in industry, often to create multi-material architectures or complex structures. Problems related to interfacial heterogeneities (composition or microstructure gradients, locating phenomena under load), which are inherent to the assembly process, will also be addressed. Approaches that combine experimentation and simulation will be encouraged, as well as the development of original processes.

Deployment of materials

For the deployment of materials through transformation or assembly processes, the objective is to match the specific features of materials with the processes used to obtain them, using simulation tools in particular. Additive manufacturing, a technique whose use will likely spread considerably in the coming years, is eligible under this theme.

B.3 – Theme 3: Molecular chemistry, sustainable chemistry and associated processes

Chemistry must meet the challenges of sustainable development and accelerate the evolution of its practices to reduce its consumption of raw materials, its energy cost and its environmental footprint. Chemical manufacturing must be moved towards a

"circular" economy based on research and innovation in chemistry and process engineering, combined with disruptive activation techniques. Eco-design, cost-benefit analysis and life cycle analysis should be integrated as far as possible at all technological readiness levels.

The proposals expected must therefore be centred on the research, development and full or partial implementation of processes leading both to existing products, molecules and materials and to new molecules and materials. Projects may address all manufacturing phases, from the selection of raw materials to the development of the reaction pathway (search for new reactivities, new activation methods, catalytic objects, "green" solvents, etc.) and associated processes.

New molecules, new reaction schemes and associated tools

This theme focuses on the design of new molecules with novel properties. Expected advances relate to research on i) atom-economical synthesis pathways, ii) alternative solutions to the use of toxic substances, or solutions leading to more environmentally-friendly products and processes, or iii) material syntheses with targeted properties. Innovations can involve new access pathways as well as original reactions, reagents and applications. Projects will also examine innovations in analytical fields. Methods need to be developed for the design and prior evaluation of reactivity at the same time as the required properties (*in silico* approach) to minimise the biological and environmental impacts. Chemical synthesis processes and pathways inspired by those performed by living organisms (enzyme-inspired catalysts, activation modes) and their translation into new reaction schemes that can be integrated into industry could be explored, with an emphasis on recycling possibilities.

Catalytic systems

This field covers ***homogeneous catalysis, heterogeneous catalysis, enzyme catalysis and their combinations.*** The expected innovations relate to the development of new, high-performance, atom-economical catalytic systems for key reactions. The contribution of multiple catalytic systems combining several types of catalysis constitutes an additional theme. Projects may also cover i) the stability of catalytic systems, preferably under extreme reaction conditions (temperature, solvent, pH etc.), ii) the influence of impurities from the substrates under consideration and iii) the effects of any poisons present, in particular to establish deactivation mechanisms and propose remedies. Special attention should be paid to the recycling of catalysts and the use of non-toxic metals and/or ligands for which availability and cost are not sensitive criteria. The development of enzyme catalysts and combinations of chemical and enzyme catalysts is also expected. All approaches (characterisation in situ/operando, kinetics, modelling etc.) that improve knowledge of catalytic steps must be considered. Combinations with other activation modes (electro- and photocatalysis, microwave, ultrasound, plasma etc.) and the development of micro- or nanoreactors are topics of interest.

Economical, intensified processes and new media

Research is expected into new methods to develop innovative, competitive and eco-efficient processes: i) process design, especially in conjunction with new activation modes, intensified catalytic reactors, multi-functional reactors etc., ii) the implementation of new technologies for unit operations as well as entire processes to

obtain economic and environmental breakthroughs, iii) the exploration of new media (new solvents, solvent-free, eco-compatible media etc.), iv) the overhaul of existing processes to improve competitiveness and environmental efficiency by implementing innovative solutions (reduced waste, recycling, improved energy balance, coupling of transfers, including emissions in the economics of the process) and v) the development of flexible processes to add value to increasingly variable material and energy flows.

B.3 – Theme 4: Polymers, composites, physics and chemistry of soft matter

Polymer and organic matrix composite materials are important in various industrial sectors (aeronautical, automotive, construction, energy, health etc.) that have direct consequences for the environment. Recent breakthroughs (self-healing, vitrimers etc.) and research to improve their thermal and mechanical properties and recycling value and to introduce functional properties bring chemists, physical chemists, physicists and engineers together, so the purpose of this theme is to stimulate proposals from these communities. Proposals should highlight innovative concepts to respond to the challenges of polymer science in the broadest sense. This theme also encourages proposals relating to the science and engineering of soft matter, where the properties are the result of interactions, structuring and dynamics at different spatial and temporal scales. To assist in choosing applicants, a limited number of headings is proposed, with a few suggestions and examples that make no claim to be exhaustive.

Polymer chemistry and synthesis

This subtheme invites proposals on the design and use of new, non-toxic monomers, oligomers and polymers, the functionalisation of natural and synthetic polymers and macromolecular chemistry as well as the development of synthesis pathways for polymer materials resistant to extreme conditions and resins for composite materials with polymerisation controllable at moderate temperatures, whilst maintaining and even reducing cycle and system times for additive manufacturing. The use of monomers and oligomers derived from biomass or the recycling of end-of-life materials is an interesting avenue, as is the development of effective methods/processes for depolymerisation and controlled degradation with recovery of the compounds obtained and modification/functionalisation if necessary so that they can be reused. Thus, proposals for material synthesis chemistries allowing for effective recycling of polymers are expected.

Supramolecular chemistry and physical-chemistry and molecular assemblies

Molecular assembly using the weak-link approach plays a key role in the field of life science (living structures at meso and macro scales, molecular recognition and receptors, enzyme-substrate interactions) and in the design of “smart” materials (with properties or functions beyond those of their constituent parts, self-healing, regulation and autonomous adaptation, recognition and supramolecular catalysis). The production of synthons enabling the construction of supramolecular organisations due to their self-assembling or self-organising properties also includes the study of the architectures or assemblies themselves, such as reversible or programmable molecular systems. Chemistry and the associated structure-property relationships may be addressed from both theoretical and application standpoints

Functional polymer and composite materials

The purpose of this subtheme is to stimulate projects proposing advances in the

development of polymer-based materials with special properties (thermomechanical, self-healing etc.) for specific applications (membranes, smart textiles, sensors etc.). It also includes innovative formulation concepts, the study and understanding of structure-property relationships and multi-scale modelling of polymer, composite and nano-composite materials with the goal of predicting their properties. The durability of polymer materials is another critical challenge for future development that should stimulate innovative projects.

Polymer surfaces and interfaces

Unlike the previous subthemes, which mainly address polymers and composites as solid masses, polymer surfaces in terms of their structuring (or nano-structuring) and their specific properties (specifically adhesive or anti-adhesive, anti-bacterial etc.) can be used to adapt a material to an application. This subtheme includes projects proposing original treatments for polymer surfaces, detailed characterisations of surface properties and innovative processes for bonding polymers to identical or different types of surface etc. Proposals relating to thin polymer films, whose thickness is comparable with the size of the species involved, fall under this theme.

B.3 – Theme 5: Nanomaterials and nanotechnologies for the products of the future

The industry of the future will be based in part on multifunctional materials and integrated measurement and detection systems. Their performance will rise as the integration of their functions at different scales (micro and macro) into their assembly is increasingly designed at the nanometric scale, for which much work remains to be done in industrial processes. Process development will require a series of crucial scientific and technological building blocks.

The presence of objects or phenomena specific to the nano scale in the final outcome of the project should be the main criterion prompting submission of the project under this Theme 5, rather than under the chemistry or materials themes. The scientific barriers addressed must be generic. More applied projects should be submitted under the ad hoc challenge.

Complex functional nano-objects

The first technological building block for the products of the future is the mass production of nanomaterials (nanoparticles, nanowires, nanotubes, core-shells etc.), which may be hybrid or composite. In the case of composite materials, the interface can itself be considered a research nano-object. The development of innovative materials and substrates for flexible optoelectronics should be regarded as a subject cutting across several possible approaches (compatibility with living organisms, adaptation to structures of variable forms, visual communication etc.). Where possible, production plans must incorporate the principles of eco-design and safe-by-design objects. The durability and life cycle of nanomaterials can also be research topics. These nano-objects may present functional properties (mechanical, chemical, biological, thermal etc.) so that they can be used in materials with new properties. For projects focusing on nanomaterials for electronic, spintronic and optical applications in information and communication technology, their design, synthesis, formulation and implementation fall under the “Stimulate industrial renewal” challenge. However, the manufacture and characterisation of devices and systems based on these nanomaterials should be directed towards the “Information and communication society” challenge. The design,

synthesis, formulation and implementation of active materials for flexible and printable electronics fall under the "Stimulate industrial renewal" challenge. However, the manufacture and characterisation of systems for flexible and printable electronics fall under the "Information and communication society" challenge.

Management of interfaces at nano scale, functionalisation, interactions between interfaces

The second technological building block required involves surface functionalisation at nanometric scale, including ultrathin films and the modification of nano-objects to give them a functional character (chemical or biological reactivity, passivation, directed interaction between surfaces, adhesion, optical and magnetic properties etc.). Dry or wet approaches can be considered. Changes to the physical properties of surfaces such as their wettability, studies on the stability of liquid/solid or liquid/liquid interfaces, fluid emulsions and the stability of polymer compounds with stabilisation or reinforcement charges are all part of this approach.

Nano-object assemblies and 2D and 3D nanostructuring

The ability to assemble or direct the self-assembly of nano-objects is a challenge that aims to obtain two- or three-dimensional functional materials. The development of processes for nanostructuring, shaping and managing assemblies of objects (electrospinning, nanostructured coatings, microfluidics, nanofluidics, rheology of nanopowders etc.) is another building block in the ability to produce new (nanostructured) products. The compatibility of nanomaterials with industrial processes may also constitute a subject of study.

Nano-objects and innovative nanomaterials for health

Fundamental knowledge acquired over the last twenty years in the physical chemistry of nanoparticles can be exploited for biotechnological applications. Projects will focus on the definition and study of innovative families of potentially multifunctional nano-objects and nanomaterials (imaging, screening, theranostics, encapsulation/vectorisation of biocompatibility, release and detection). Projects may incorporate biological proofs of concept. Proposals prioritising biological study should be addressed to the scientific themes of the "*Life, health and well-being*" challenge.

Whichever obstacles are targeted, projects focused on the fight against cancer, HIV/AIDS and viral hepatitis cannot be submitted if these topics are dealt with by the French National Cancer Institute (INCa) or the French National Agency for Research on AIDS and Viral Hepatitis (ANRS).

B.3 – Theme 6: Sensors, instrumentation

This theme welcomes proposals whose main objective relates to the huge field of sensors and instrumentation for the online monitoring of processes, the characteristics of materials and the industrial domain more generally. It includes three major subthemes:

Measurement methods and instrumentation

The design and use of sensors whose sensing element is micrometric or larger (without nano-structuring or surface functionalisation of nanometric thickness) for process monitoring falls under this subtheme. Increased material quality and productivity

requires better control of their deployment. This involves online monitoring of the characteristics of manufactured materials so that operating conditions can be adjusted in real time. The development of online characterisation and diagnostics is essential to obtain this data. This theme will seek disruptive projects, in terms of either the detection technology or the modes of action on the process.

Characterisation at the nanometric scale. Characterisation of nanomaterials

Characterisation at the nanometric scale requires specific instrumentation to meet the needs of observation and detection metrology. Proposals relating to the development of instruments or instrumental methodology in this field are therefore expected. The detection and counting of nano-objects in complex environments, fluid or solid, diluted or not, and associated methodologies are challenges included in this subtheme, along with combining technical analyses on the same object or point. Any type of physical property can provide the basis for these instruments.

Innovative sensors at the nanometric scale

Proposals under this subtheme must focus on the potential breakthrough brought by the nanometric scale to the performances of sensors/actuators in terms of detection (physical, chemical, biological), sensitivity, specificity, localisation or action. The project should extend beyond just the manufacture of materials and the characterisation of their sensitivity to a parameter (physical or otherwise) and envisage integration for instrumentation purposes.

B.3 – Theme 7: Chemistry: analysis, theory and modelling

This theme welcomes proposals where the core research is governed essentially by a **basic approach** to the **chemistry** disciplines relating to the ERC-PE04 sector (PE04_02: "*Spectroscopic and spectrometric techniques*"; PE04_05: "*Analytical chemistry*"; PE04-07: "*Chemical instrumentation*"; PE04_09: "*Method development in chemistry*"; PE04_13: "*Theoretical and computational chemistry*").

It also deals with specific aspects of chemical instrumentation not covered by the other themes in the "Stimulate industrial renewal" challenge.

B.4 – Research to be conducted in response to the "Life, health and well-being" challenge

Introduction

The "Life, health and well-being" challenge offers enormous potential for pushing back the frontiers of knowledge and transferring the results to individuals and society. This challenge is also a driver for innovation and economic growth in the industry sectors of biotechnology, pharmaceuticals, diagnosis and medical devices.

The National Research Strategy sets out two priority areas for this challenge: "multi-scale analysis of the diversity and evolution of living organisms" (priority area 16) and "biological data collection and processing" (priority area 17).

The ANR Work Programme 2018 offers 12 themes (three corresponding to multiple challenges: see section B.11). Most of them are cross-disciplinary and several are multidisciplinary. They are all **very open to proposals for basic research.** They are divided between three broad fields:

(i) decoding the mechanisms of life, physiology, development and ageing, the fundamentals of genetic diversity. Initiatives should go beyond the descriptive stage of genome observation and sequencing to address the understanding of functional mechanisms and their disorders.

(ii) understanding pathological processes with a view to preventing, treating or compensating for disabilities. This involves medical innovation, such as identifying new biomarkers or innovations in cell, tissue or whole-organism imaging, new therapeutic targets and molecules, innovative high-content, high-throughput screening methods, pharmaceutical and pharmacological innovations, biotherapy for repair, regeneration and replacement, biomaterials and technological research in e-health and telemedicine.

(iii) knowledge about determinants of public health and health-oriented social sciences to describe the causal chains of socioeconomic, gender, environmental and cultural inequalities, health crises, the impact of chronic diseases on individuals and their environment, social, economic and political dynamics relating to health innovations and healthcare regulation and finally methodological research, regardless of its field of application.

ANR finance supplements funding from other bodies. The health portal (www.aap-recherchesante.fr) provides information on all calls for proposals published in France in the field of health and sets out the specific features of each one. For example, ANR does not fund research into cancer, HIV/AIDS and viral hepatitis or certain environmental aspects of health. These themes are the responsibility of INCa, ANRS or ANSES. Projects in these fields that incorporate a partnership with industry or an international partner may nevertheless receive ANR funding, along with projects submitted for ERA-NET-type calls for proposals open to these themes. Clinical research projects should preferably be submitted under the hospital clinical research programme (PHRC), and research projects on health and care systems should be submitted under the healthcare performance research programme (PREPS) run by the Directorate-General for Healthcare (DGOS).

ANR also proposes international and European initiatives under the "Life, health and well-being" challenge. The relevant calls for proposals can be consulted on the agency's

website.

B.4 – Theme 1: Biochemical and structural approaches

This theme seeks to characterise the molecular mechanisms and machinery involved in the functions and malfunctions of living systems. Research under this theme draws on a variety of fields, including biochemistry, structural biology, chemistry, molecular biophysics, imaging and bioengineering. The theme is broken down into two subthemes that will be dealt with by two separate evaluation panels.

- ***The characterisation of the structures and structure-function relationships of biological macromolecules***: The challenge here is to decode and predict the structures of biological macromolecules and their complexes and to characterise the dynamics of their interactions using isolated systems or systems reconstituted in vitro or in their cell context. Technological developments in structural biology (NMR, crystallography, cryo-electron microscopy etc.), imaging (super-resolution microscopy, correlative microscopy etc.), molecular dynamics or single-molecule approaches are also considered in this theme.
- ***The biochemistry of living organisms***: This involves characterising and modelling the chemical and biochemical transformations performed by the cell. This subtheme therefore relates to enzymology, pharmacology and toxicology, studies on metabolism and bio-energy and analytical and "-omic" approaches, including quantitative proteomic and metabolomic analyses and microbiota studies. The field also includes approaches to acting on living organisms and their application to the detailed analysis of functional biology and human health mechanisms (probes, inhibitors, ligands, molecules for diagnostic or therapeutic purposes). Lastly, it covers the design of new biological systems (synthetic biology) and the controlled alteration of metabolic pathways in an attempt to understand the fundamental mechanisms of living organisms or develop biotechnological applications.
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B.4 – Theme 2: Genetics, genomics and RNA

This theme seeks to comprehend the genetic and epigenetic foundations of how various living organisms function, the mechanisms that control gene expression, the genetic defects and gene expression defects behind cell malfunctions, pathologies in animal or plant models and human diseases.

The aim of this theme is to:

- Characterise genome and epigenome variability and the mechanisms behind it, the mechanisms responsible for genome integrity, the faithful transmission of genetic information and the principles of genome organisation and evolution.
- To understand RNA replication, repair, transcription, maturing, transport and translation processes and transcriptional, post-transcriptional and translational regulation/deregulation.
- Characterise and understand the mechanisms by which chromatin organisation originates and its epigenetic modifications, including the role of non-genic

genetic entities, non-coding DNA, the 3D organisation of genomes and the regulating role of non-coding RNA.

- Study and characterise the genotype-phenotype relationship and the role played by exposome components in this relationship, in conjunction with the environment.

B.4 – Theme 3: Cellular biology, developmental biology and evolution

This theme seeks to:

- Understand elementary biochemical and biophysical mechanisms at the scale of bacterial, animal and plant cells: cell cycle, biogenesis and the dynamics of intracellular organelles and the plasma membrane, the molecular mechanisms of senescence, ageing and cell death, signalling, from reception of the signal to its transduction, homeostasis and the differentiation of different cell types, maintenance and differentiation of stem cells, cell adhesion, cell movement and cell migration.
- Understand these mechanisms at the scale of tissues in the organism or in multicellular systems reconstituted in vitro (organoids) to decipher the basic principles of the morphogenesis of animal and plant tissues, cell homeostasis, the development of multicellular eukaryotic tissues and organisms, prokaryotic cell colonies and tissue ageing.
- Understand these mechanisms in the context of species evolution and adaptation to environmental conditions.

The use of innovative technologies in genetics, ex vivo tissue engineering, microscopy, quantitative biology and modelling to highlight original biological principles is encouraged.

B.4 – Theme 4: Physiology and physiopathology

This theme seeks to:

- Understand the hierarchical assembly of molecular and cellular components of tissues and organs and the underlying signalling pathways (including metabolic), their interactions and the physiological properties generated by these interactions.
- Understand these interactions and properties within organisms as a whole and at the interface with the environment, including the microbiota.
- Understand the mechanisms of their alteration in pathological processes.
- Support projects addressing all the determinants (biological, behavioural, psychological and social) underlying physiological and/or pathological functioning (especially in metabolic pathologies and nutrition).

B.4 – Theme 5: Immunology, infectiology and inflammation

Given the increasing incidence of immune, inflammatory, allergic and tolerance breakdown pathologies, the purpose of this call for proposals is to characterise the molecular and cell mechanisms involved in the organism's defences and inflammatory reactions during adaptive and innate responses, in order to compile a comprehensive analysis of the immune system in normal and pathological situations. Research aiming

to characterise the molecular fundamentals and functional pathways involved in pathologies concerned with immunological mechanisms, to improve vaccine effectiveness and protect the organism against adverse immune responses will also be funded. The development of new animal models and studies aiming to better understand the evolution of autoimmune, immunoallergic or inflammatory pathologies, response to infections and the role of the microbiota, along with software assisting in modelling responses, is included in this call for proposals.

New active or passive immunotherapy strategies and their modelling can be submitted under the "Healthcare technologies" theme (section B.4 – Theme 9).

B.4 – Theme 6: Molecular and cellular neuroscience; developmental neuroscience; integrative neuroscience

This theme covers three areas of research:

Molecular and cellular neuroscience/developmental neurobiology

Understanding the logic of the hierarchical structure of the thousands of molecular, cellular and tissue components of the nervous system and sensory organs, how their dynamics and plasticity generate the nervous system's functional properties (e.g. the neural code).

All studies undertaken at the molecular and cellular scales designed to understand the mechanisms governing the development, functioning, dynamics and plasticity of the nervous system and normal or pathological sensory organs.

Understanding the mechanisms and identifying the molecular and cellular determinants involved in psychiatric illnesses, addiction and neurodegenerative diseases. The neurovascular and neuroinflammatory components of these pathologies are also included, except for non-neuronal aspects.

This panel considers all invertebrate and vertebrate animal models (excluding non-human primates), together with the experimental and technological approaches associated with these studies and their development (imaging, computation and models, behaviour, electrophysiology, pharmacology, optogenetics, etc.).

Integrative neuroscience

This subtheme covers all studies at integrative scale designed to understand high-level brain properties and specific aspects of the human brain, including its social and pathological dimensions.

It also focuses on understanding the different levels of hierarchy and interactions specific to the functioning of the brain (e.g. neural ensembles, ensemble networks, integrated actions), without which it is impossible to address high-level brain properties (e.g. multisensory integration, recognition of objects and actions, decision-making, memory, behaviour, cognition), as well as aspects specific to the human brain, including the social dimension (e.g. self-awareness, perspective, deliberate thought, language and relationships with others).

Projects will address the full range of expressions of mental health, psychiatry and addiction. The goal is to encourage complementary aspects and synergies between basic research, preclinical and clinical research in the area of mental health, psychiatry and addiction. The epidemiological approach to health inequalities in mental health falls

under the inter-challenge "*Public health*" evaluation panel common to the "*Life, health and well-being*" and "*Innovative, inclusive and adaptive societies*" challenges, whereas the sociological or economic analysis of these inequalities (access to healthcare, medical insurance coverage, vulnerabilities, determinants associated with social capital and care provision) comes under the "*Innovative, inclusive and adaptive societies*" challenge. Connected devices are covered by the evaluation panel for the "*Information and communication society*" challenge (theme 9).

This area also covers nervous system pathologies including cerebrovascular diseases and diseases of the sensory organs, excep for non-neural aspects.

The models studied could therefore be rodents, non-human primates and humans; the experimental approaches include functional and multimodal imaging in vivo (MRI, fMRI, PET, photonics), electrophysiology, computational analyses, behaviour, optogenetics, psychophysics, etc.).

Mental health, psychiatry and addiction

Projects will address the full range of expressions of mental health, psychiatry and addiction. This theme aims to encourage complementary aspects and synergies between basic research, preclinical and clinical research in the area of mental health, psychiatry and addiction. The epidemiological approach to health inequalities in mental health falls under the inter-challenge "Public health" evaluation panel common to the "*Life, health and well-being*" and "*Innovative, inclusive and adaptive societies*" challenges, whereas the sociological or economic analysis of these inequalities (access to healthcare, medical insurance coverage, vulnerabilities, determinants associated with social capital and care provision) comes under the "*Innovative, inclusive and adaptive societies*" challenge. Connected devices are covered by theme 9, "*Information and communication society*", of the "*Life, health and well-being*" challenge.

B.4 – Theme 7: Translational health research

The objective of this call for proposals is to fund collaborative projects on scientific issues at the interface between basic and clinical research. This initiative to incentivise translational research aims to fund studies positioned downstream of exploratory research projects carried out in research laboratories and upstream of clinical research projects supported by the Hospital Clinical Research Programme (PHRC) run by the Directorate-General for Healthcare Provision (DGOS).

This translational research theme is designed to break down the boundaries between upstream and downstream areas, especially in terms of physiopathology. The project results must enable the formulation of new hypotheses that can be tested in clinical research. Applicants who wish to seek joint ANR-DGOS funding for their project under a potential "Translational Health Research Programme" (PRTS) joint initiative should submit their project under this theme.

B.4 – Theme 8: Medical innovation (nanotechnology, regenerative medicine, innovative therapies and vaccines, diagnostic methods and biomarkers)

This theme targets proposals for applied biological and biomedical research projects as outlined in the title. It focuses particularly on three types of projects: (i) projects to develop emerging technological concepts (including new therapeutic targets), (ii) relevant technological design or development projects with a view to industrial transfer

(proof of concept) and (iii) projects aiming to develop and transfer knowledge between industrial and academic partners in the health field in order to strengthen French competitiveness in the biomedical sector.

B.4 – Theme 9: Healthcare technologies

This theme covers the sectors of health and independent living, which are crucial for medical progress. It also includes the medical devices associated with diagnosis, care, prevention and compensation for disability or loss of independence. The inter-challenge panel common to the "Life, health and well-being" and "Information and communication society" challenges will evaluate projects whose dominant focus is to develop mathematical and IT tools for biomedical or clinical purposes (section B.11 – Theme 1).

Two project types will be encouraged: (i) projects with high innovation potential combined with knowledge acquisition or technology design or development with a view to industrial transfer and (ii) projects aiming to develop and transfer knowledge between industrial and academic partners in the health field in order to strengthen French competitiveness in the health technology sector. Projects focusing on research methods tools for industrial development are also relevant to this theme.

B.5 – Research to be conducted in response to the "Food security and the demographic challenge: biological resources, sustainable operation of ecosystems and the bioeconomy" challenge.

Introduction

Research under this challenge relates to food security, the sustainability of agricultural, forest, aquaculture and marine ecosystems and the bioeconomy. It is partly directed towards achieving UN sustainable development goal 2, "Zero Hunger", and the terms and ambitions of the Paris climate agreement.

Food security means ensuring the world's population has access to enough healthy, balanced and nutritious food to satisfy its needs and food preferences. Ensuring food security should not detract from the other interdependent sustainable development goals, including reducing inequality, access to energy and water, protecting biodiversity, fighting land degradation and combating climate change.

In the face of global change, food and non-food systems using biomass are undergoing or must undertake significant transformations. This involves both reducing the ecological footprint of agricultural, forestry, livestock, aquaculture and fish production and processing and adapting these sectors to current global changes: climate change and biodiversity loss, the expanding world population, changes in biomass consumption practices and the globalisation of trade. All these factors exert growing pressure on production systems. They generate increased health risks and have potential repercussions for human health.

The development of the bioeconomy, as laid down in the relevant French strategy, can make a considerable contribution to addressing these issues: complementary food and non-food use, new joint models for the use of bioresources, optimisation and reuse in a circular economy, new modes of economic and territorial organisation and governance etc.

Biological resources, fundamental components in the functioning of these systems, must be studied to determine both their intrinsic properties and their ability to respond to these objectives.

To achieve these goals, challenge 5 calls for systemic, cross-disciplinary and applied research and innovation and exploratory cross-disciplinary research to produce fundamental knowledge. Research areas include biological resources, biomass, productive ecosystems and food systems and will target in particular the production of new bioresources, new practices, new social organisations and new markets.

The work relates to different organisational levels and spatial and temporal scales, from the gene to the individual, from the individual to the population and then to the ecosystem, from local solutions to global coordination and from short-term decisions to long-term objectives. Research may also focus on the links between these scales.

These complex, interlinked areas draw on the life sciences, soil science and agronomy, social sciences, humanities and physical sciences for the processing of bioresources.

B.5 – Theme 1: Animal biology, photosynthetic organisms and micro-organisms of interest for biological resources and their specific models

Ensuring food security and the supply of biomaterials (wood, fibres, high-added-value molecules etc.) for a growing population in a context of global change whilst helping to improve the environment or mitigate the impacts of agricultural, forestry, fishery and aquaculture activities on the environment and climate requires the development of productive living organisms, contributing to economic, environmental and social performance and adapted to these changes, while promoting biodiversity.

B.5 – Theme 1 – Subtheme 1.1: Core knowledge about the biology of organisms of interest for biological resources, their specific models and associated organisms

To advance the boundaries of science in response to these challenges, research is expected into the basic biology of **livestock and food-producing animals**, **photosynthetic organisms of interest and their specific models and associated organisms** (micro-organisms, microbiota, pests, beneficial organisms etc.).

Research may cover a continuum of organisational scales, from gene to population, and investigate all levels of regulation (genomic, transcriptomic, epigenetic, translational, post-translational, metabolic, physiological etc.).

Methodological developments for data integration, genome editing and modelling approaches are included. Research will be able to draw on complementary approaches including systems biology and synthetic biology.

For animal biology, research may aim to:

- better understand the **construction of phenotypes and behaviours**, including by comparing genotypes/phenotypes of neighbouring species and the neurological mechanisms involved in animal welfare;
- explore **the mechanisms regulating compromises** between these different functions of interest and develop **a systemic approach to interactions**.

For plant biology, research may aim to:

- **investigate the processes for CO2 assimilation and adaptation** to environmental stress, including combinations of stresses);
- identify **metabolic networks**, the genes involved and their regulation and signal transduction pathways, including hormonal pathways;
- study **the interactions between organisms**, **the interrelationships** between abiotic environmental variations and the development of favourable or unfavourable biotic interactions.

B.5 – Theme 1 – Subtheme 1.2: Animal biology, photosynthetic organisms and micro-organisms of interest for biological resources: adaptation and reduction of inputs

Applied research projects are expected, aiming to:

- Characterise biodiversity, develop, structure and protect **genetic resources** (natural and induced), select varieties and breeds that use resources more efficiently, are more environmentally-friendly or limit the environmental impacts, including the study of associated microbiota and **genomic selection;**
- Encourage diversity within and between livestock and food-producing animal species to improve feed efficiency, resistance to disease, robustness and resilience to environmental change and to limit environmental impacts;
- Define the **adaptation characteristics needed for farmed living organisms in response to long-term global changes** and/or conditions for mitigation;

- Integrate **varieties and breeds with specific characteristics** (proteins, sugars, lipids, metabolites) into renewed production systems (agroecology, agroforestry, new husbandry systems, aquaculture etc.);
- Use **translational biology** to transfer the knowledge accumulated from model species to farmed living organisms and other usable species;
- Develop and evaluate **renewed or alternative production models** that are more suited to local conditions, concerned about ethics and sustainability and that ensure animal welfare;
- Optimise **methods** for **transforming genomes**, their expression and their selection;
- Use **modelling for more integrative, predictive biology**.

B.5 – Theme 2: Nutritional biology, food, healthy and sustainable food systems and global food security

Food systems are faced with changes that test their sustainability. More sustainable food must satisfy growing demand by developing production systems in line with the objectives of the three pillars of sustainable development. This means offering food products that meet consumer needs in terms of health, nutrition, taste, culture and ethics, are accessible to all and support welfare, health and the environment. Cross-disciplinary and/or systemic initiatives specific to the issues of the bioeconomy fall under the inter-challenge "*Bioeconomy: specific technologies and systemic approaches*" theme.

B.5 – Theme 2 – Subtheme 2.1: Nutritional biology and food science

Basic research projects expected under this subtheme may cover disciplines and fields including:

- **Nutritional biology** (epidemiology, intervention in humans, early risk biomarkers, preventive nutrition and nutrigenetics, interactions between foods and the digestive tract, human microbiota, regulating the energy balance etc.);
- **Microbiology, virology, mycology and parasitology** in food and water (pathogenic power of micro-organisms, host-micro-organism relationships, microbiota and complex ecosystems, functions and services, associated benefits or risks and their evaluation etc.);
- **Physical chemistry of the food matrix** (molecular interactions, transfer of matter and heat etc.);
- **Sensoriality** (neurobiology of perception etc.).

B.5 – Theme 2 – Subtheme 2.2: Evolution of technologies, behaviours, sectors and public policies for healthy and sustainable food

This evolution relates to all practices from agricultural, fishery and aquaculture production to food manufacture and distribution and consumption behaviours. Agri-food companies need to innovate to respond to the rapid changes in this context and the requirements of sustainable food systems, whilst controlling the quality and competitiveness of manufactured foods.

Research will focus on the design of the food supply chain, especially the food processing, formulation and conservation stages, their impacts on health and the environment, on the analysis of consumer behaviours and on the involvement of public policies and business strategies. Multidisciplinary approaches are expected on the following themes:

- **Innovative technologies and processes in food production**: process flexibility in line with the variability of raw materials, automation and robotisation to improve performance and reduce musculoskeletal disorders, cost control and tools to assist expert analysis;
- **Optimised resources at industrial scale**: promotion of biodiversity, reduced waste and consumption (water, energy, raw materials, packaging etc.), process eco-design, active, eco-designed and functional packaging, life cycle optimisation and reuse of by-products and waste (circular economy);
- **Safety of the food chain**: pathogenic and spoilage organisms, chemical and immunochemical hazards, methods of evaluating hazards and assessing risks, food conservation;
- **Interactions between food and the microbiota**: control of food microbiota accompanying food processing, mainly for the properties given to these foods and the effects of microbiota introduced into the gut microbiome;
- **Determinants of food preferences and consumption practices**, aiming to facilitate a healthier and more environmentally-friendly lifestyle. Priority will be given to field experiments. Research into the operation of public policy incentives is encouraged;
- **Foods and diets for preventive nutrition**: priority will be given to projects relating to the elderly, newborn babies, children and vulnerable populations. Priority will also be given to integrative biology approaches and to projects incorporating several nutritional determinants (sensory, nutritional, health, social and economic);
- **Foods and diets for preventive nutrition**: priority will be given to projects relating to the elderly, newborn babies, children and vulnerable populations. Priority will also be given to integrative biology approaches and to projects incorporating several nutritional determinants (sensory, nutritional, health, social and economic);
- **Design and performance of public policy**: impact analysis and levers for public policies targeting players in food systems (companies, consumers, new players etc.).

B.5 – Theme 2 – Subtheme 2.3: Global food security

Food security covers the four key dimensions set out by the FAO: (i) availability of food through agriculture, fishing and aquaculture, (ii) food utilisation and the nutritional situation of populations, (iii) economic and physical access to food and (iv) the stability of availability and access over time. A further dimension should be added relating to food security policies and governance. These various dimensions need to be (re-)examined in the light of current global changes: climate change, depletion of natural resources, transitions (demographic, nutritional, energy and socio-political). In particular, research should cover:

- **Quantitative/qualitative balance between food demand and supply**: modelling that incorporates the effects of global change (agricultural productivity, production systems and technologies, land use and the state of soil resources, the effects of nutritional transitions, industrial strategies, public policies, urbanisation, environmental hazards, agricultural market instability);
- **Public policies and governance of food security**: governance policies and instruments promoting food security at different levels, conditions for the emergence of these policies, organisations targeting food security, consistency and coordination of public policies relating to food security and the protection of natural resources;
- **Determinants of food access**: household food strategies, the links between work and income systems and food access, food security in a climate of instability, the food situation and nutritional state of vulnerable populations, innovative forms of organisation that facilitate supply security, local marketing circuits;
- Food transitions: changes in diet due to changes in lifestyle, food product supply, economic growth, migrations and urbanisation, environmental and health awareness, economic, social, health and environmental impacts of nutritional transitions, public policy instruments that limit the detrimental effects of transitions and are adapted to economic, social and cultural contexts.

B.6 – B.2 – Research to be conducted in response to the "Mobility and sustainable urban systems" challenge

Introduction

Research submitted for the "Mobility and sustainable urban systems" challenge should explore ways in which urban systems, transport, housing and their users can adapt to the need for sustainable development. The challenge particularly stresses integrated and systemic approaches to the analysis of societal and environmental processes in their interactions and complexity. Mobility, habitat and coexistence more generally should be considered in the light of environmental pressures, ecosystem services, the reduction of nuisance factors and the global changes that are already happening or are predicted in the medium and long term. Without losing sight of vulnerabilities and potential social inequalities, research should assess and improve the performance of buildings and transport, as well as the organisation of urban systems. Particular attention will be paid to advances made by the digital society to support, develop and promote more sustainable mobility and smarter urban management while ensuring sustainable and adaptable infrastructure and networks meeting existing and emerging needs. Governance procedures and the development of public policies that play a role in the management, evolution and promotion of urban systems must be analysed in light of these objectives.

Research undertaken in this framework must pursue several scientific objectives:

- Constitute new bodies of knowledge focused on energy efficiency, environmental impacts and quality of use for components such as vehicles and buildings at different scales, examining the interactions between these criteria and the scales;
- Develop modelling of physical and social objects and their interactions as well as data management to support design, decision-making and performance assessment;
- Explore how digital technologies can cause changes to mobility, housing, urban systems and user behaviour;
- Assist in developing methodological and technological solutions to design, build, renovate and adapt urban systems to the new energy and environmental requirements and to uses;
- Contribute to discussions and the development of innovative approaches to planning (see the Horizon 2020 "nature-based solutions" and "integrated cities" themes).

B.6 – Theme 1 – Subtheme 1.1: Fundamental knowledge, exploratory research and disruptive concepts

This first subtheme, cutting across the other subthemes, aims to produce **fundamental knowledge relevant to the challenge** or to enable the exploration of **radically new ideas and approaches and disruptive concepts** relative to more incremental research. Basic or very preliminary research is necessary to help constitute a core of knowledge as a basis for public policy and future technologies.

For example, contributions are sought:

- On conceptual approaches (notion of the sustainable city, urban theories etc.)
- In the sociology of socio-technical systems and the dynamics of change
- In systems theory and optimisation, applied mathematics, advanced modelling, algorithms, high-performance computing and the use of big data
- In methods, tools and technologies for the collection and analysis of urban and regional data
- Adopting biomimetic or bio-inspired approaches, both to develop of products and to model the urban metabolism and its environmental and energy footprint, or for mobility management

On the interdisciplinary integration between the humanities, social sciences, engineering and environmental sciences and the relationship between technical and political determinisms of the city.

For projects submitted under this theme, the research subjects, applications or goals (even long-term) are expected be positioned in relation to at least one of the following subthemes, indicating how they can contribute to the issues described below.

B.6 – Theme 1 – Subtheme 1.2: Sustainable cities and territories

The city is a complex, integrated system; acting as effectively as possible on this system demands both targeted research into knowledge gaps and integrated multi-sector, cross-disciplinary approaches.

Socio-spatial approaches to sustainability (mobility, development, practices)

Urban dynamics, **transitions** and interactions between the short and long terms and the local and global scales are still poorly understood, despite their key role in urban sustainability. The aim here is to improve our understanding of the **factors in urban evolution** (growth, decline, economic and social attractiveness etc.) that can help to consolidate or weaken urban systems, boost the links between cities, towns and low-density areas, raising the question of the location of populations and economic activities (city centres, suburbs, rural areas, small or large conurbations etc.). In this perspective, it is important to revisit the links between **urban forms**, **organisations of the urban fabric**, the **location of activities**, **transport and infrastructure services**, **mobility** and **environmental impact**. Research should shed light on the controversies, frictions and power relations relating to **densification**, **compactness**, functional, social and generational **diversity**, **multipolarity** etc. in developing urban sustainability. As these are phenomena for which the spatial and time scales are interlinked, the methodological challenge is a steep one. Modelling is a promising path to be developed, but other methods (scenarios, international comparisons etc.) should also be explored or revisited.

The **habits of urban service users** are gradually changing, influenced in particular by greater awareness of **environmental issues** and the **spread of digital technology**. Other factors, such as economic crises, are also contributing to these changes. However, gaps and even contradictions persist between more eco-centred perceptions and practices that are still often resource-intensive. Identifying, understanding and managing the tensions inherent in the introduction of sustainable approaches to mobility, housing, the use of public spaces etc. constitute a research field in their own

right.

Mirroring the questions on **well-being** and **quality of life**, research on urban sustainability calls for converging research on changing urban lifestyles and relationships between societies and their environment. It involves intersecting contributions from ecology, geography, history, sociology, anthropology, psychology, economics, law and political science.

Environmental quality, ecosystem services and optimum use of resources

Cities consume vast quantities of materials and energy, with corresponding emissions of waste into the water, air and soil. It seems essential to gain a better understanding of the processes involved in this **urban metabolism**. The underlying issues do not just involve understanding, managing and controlling how towns and cities function, how they **interact with the biosphere** and their **impact on the environment and humans** (pollution, waste, land use conflicts etc.); they also raise questions about closed-loop flows, symbiosis between urban, agricultural and industrial processes, short supply chains, resource efficiency etc.

Issues of **urban environmental quality** linked to the health and welfare of residents require careful characterisation of the multiple exposures of populations to different types of **pollution** and **nuisances** (particulates, noise, smells, degraded landscapes etc.), in all areas of the city (open or confined) – and their consequences.

Quality of life and environmental quality aspects must be explored in conjunction with technical developments, particularly in the field of energy.

Although understanding of certain roles played by **nature in towns and cities** is beginning to improve, research to produce new knowledge on **biodiversity** and the workings of **urban socio-ecosystems**, including urban agriculture, is still needed to form a solid basis for **urban ecological engineering**. These socialised, artificialised, "natural" ecosystems provide a wide range of services, including provisioning, regulation, social and cultural services, amenities and mitigation of nuisances. Lastly, research will shed light on the dual causal relationship between the functioning and quality of urban ecosystems and **human well-being**. Three fields of investigation should be considered: the value of non-market goods and services and their monetary values (**ecosystem services**), the role of access to high-quality information in the value attributed to ecosystem goods and services by society; social feasibility and the participatory mechanisms to be considered in sustainable urban governance. In particular, the potential for resilience or adaptation associated with maintaining a certain level of biodiversity, both for the environment and for economic activity and well-being, could be evaluated.

These studies could lead researchers to consider the relevance and operational nature of human development indicators.

Vulnerability and resilience of urban systems

Issues of urban **vulnerability** to sudden events (floods, heat waves, riots etc.) and to gradual changes (slow impacts of climate change, ageing population), **resilience** and **adaptation** need to be addressed from systemic viewpoint. On one hand, research must identify, qualify and quantify the fragility of urban systems, and on the other it must develop approaches for assessing their overall vulnerability. The introduction of solutions for resilience, or even better, adaptation is a key issue in terms of both

knowledge and operational requirements. The issue of the vulnerability and resilience of urban systems will take into account land use and regional development policies, their traditions and inertia, their ability to adapt and current and future land use conflicts.

Attention should also be paid to vulnerability and resilience as factors in the **economic dynamism** and **attractiveness** of urban systems and regions more generally: type and range of activities, exposure to risks, promotion of a circular economy, policy for welcoming and accommodating new businesses, tourism and cultural policy etc.

B.6 – Theme 1 – Subtheme 1.3: Sustainable construction

From low-carbon, low-environmental-impact buildings to blocks or districts

The targets for improving the **energy efficiency of the building stock** are extremely ambitious. Nevertheless, research is still required on the appropriate spatial and temporal scales to reduce energy consumption in buildings: the **block** and the district, for example, are potential integration scales to be investigated.

At the same time, regulations in the building sector are set to replace best-efforts obligations with guarantees based on results. This exchange will offer greater freedom of choice while encouraging technical and architectural innovation. It will also require the development of **physical measurement** methodologies and instruments, which are essential for energy audits and performance monitoring. Many **building design tools** and **models** rely on theories rendered obsolete by the new energy performance targets, partly because previously neglected secondary phenomena are acquiring importance in this new context. It is important to review these tools for design, construction and renovation (digital models). They should address not only energy but also issues related to health (air quality, noise etc.), comfort (multiphysics approaches, acoustics, lighting etc.) and interactions and feedback mechanisms between technical systems and users. This will require a better understanding of **behaviours** and the **qualities and values of building use** through strengthened dialogue between social sciences, humanities and engineering and environmental sciences to improve predictions of actual building and city block performances. The aim is also to design buildings and blocks that are easier to adapt and more robust in terms of performance when used for a wide range of purposes, taking users' practices and values into account from the beginning. Lastly, an important research field relates to **economic models** and the methods for the dissemination and uptake of these innovations, both by stakeholders in the building industry and by users, particularly in the redevelopment/renovation sector.

Civil engineering, sustainable construction and management of built heritage and infrastructure

Over and above strictly energy-related issues, the **overall sustainability of built heritage** (buildings and infrastructure) remains a major challenge for sustainable development. The primary concern is to improve knowledge about the mechanisms of **ageing**, loss of performance and risk of failure in this heritage, as well as to suggest tools and methods for **monitoring, inspection, specification and modelling**. Solutions for **eco-design**, **construction**, **maintenance**, planning, inspection, management, prevention and protection against natural hazards need to be improved or reconsidered. It is also important to review the origins and the technical and environmental qualities of the materials used, low-cost, high-performance **renovation/re-engineering technologies** and intervention methods for buildings, transport infrastructure and networks, limiting the time for which these structures are out of service and taking

account of current and future scarcity of materials, space or land, the potential impacts of climate change and life cycle analyses.

Special attention should be paid to the preservation and enhancement of cities' cultural heritage, a source of differentiation and attractiveness, when proposing projects to redevelop city blocks or districts.

B.6 – Theme 1 – Subtheme 1.4: Clean, safe, connected and automated vehicles

Energy efficiency of vehicles: powertrains and global approaches

Reducing the environmental impact of transport is largely dependent on overcoming the scientific and technological hurdles that are preventing the widespread introduction of vehicles (private, community and utility) with low emissions of greenhouse gases and local pollutants. This development will require research efforts focused on **powertrains with very high efficiency and low pollutant emissions**, **emission control systems**, the use of **fuels emitting less greenhouse gas** than hydrocarbons from petroleum (including biofuels, gaseous fuels with high H/C ratios, hydrogen) in internal combustion engines, **vehicle electrification and hybridisation**, thermo-management, energy recovery and **on-board energy management**. Researchers must also consider more global approaches, such as **reducing vehicle weight**,[4] **reducing friction** and improving **vehicle aerodynamics**.

Vehicle safety, security and adaptation

Improving **road safety** (reducing the number and severity of accidents and their consequences) remains an important issue. This will mean developing new types of vehicle that are more **accessible** and **ergonomic** and better suited to changing demands, or more integration of passive and active vehicle safety technologies. But knowledge of **accidentology** must also be expanded in order to craft more effective public policies in this field. Certain issues need to be developed further: the impact of an ageing population, vulnerable road users, two-wheelers, driving distractions, the emergence of new means of transport etc. The specific features of road safety in cities have to be taken into account in a new context marked by the rise of "soft transport", the diversification of modes of mobility and the increased complexity of managing public urban spaces.

Driving aids, automation, connectivity and reliability

The development of **driving aids** (man-machine interfaces, sensors, etc.) and systems for communicating between vehicles and with infrastructure (connected vehicles), extending as far as the development of **self-driving vehicles**, is part of this context of improving **transport efficiency** and safety (by road, rail, inland waterway, sea and air). These developments can only have a real impact if the expectations and behaviours of users and drivers, together with vehicle usage constraints and interactions between vehicles with varying levels of automation and people (users and pedestrians alike), are taken into consideration. Interdisciplinary approaches combining the humanities and social sciences (psychology, sociology, etc.) with engineering sciences (ergonomics, robotics, artificial intelligence) are particularly encouraged under this theme.

Lastly, the **reliability of vehicles' on-board systems**, especially electronics and

[4] Projects relating to the design, manufacture or study of the physical or mechanical properties of materials must be submitted to the scientific evaluation panel on materials associated with the "Stimulate industrial renewal" challenge.

information and communication technologies, must also be strengthened, especially in the context of liability (manufacturer, driver, user etc.).

B.6 – Theme 1 – Subtheme 1.5: Networks and services

Networks and services for transporting people and goods

Research should contribute to rethinking **transport systems** as a whole to make them more efficient, as well as better suited to the mobility needs of people and goods. This should be based on information technologies, the organisation of services to foster cooperation, pooling, multimodality and interoperability, the optimised operation of transport infrastructure, real-time traffic management and the organisation and involvement of transport operators. But although the user-customer must be at the centre of these concerns, it is also important for researchers to question the notion of mobility needs and how to strike a balance between supply and demand within financial limitations appropriate to the economic and social context. This involves assessing new combinations of **regulatory** measures, bringing together regulation, economics and psychology ("nudges") to optimise mobility and reduce network congestion and environmental damage (noise, pollution, greenhouse gases and odours). The development and evaluation of **new services** based on a proper understanding of the dynamics of the changes affecting both personal mobility (vehicle sharing, service vehicles etc.) and procurement for households and businesses (benefits provided by the concept of the **Internet of Things** – IoT) are areas of research for this field.

Resilient urban networks and services suited to users' needs

Towns and cities work on the basis of a pooling of networked **urban services** (sanitation, water, energy, waste, Internet, transport etc.). Apart from the tools (inspection, maintenance and repair strategies etc.) needed to keep these **legacy networks** in operation, questions arise over the evolution of these services and the production of new services better suited to new constraints (energy savings, budgetary constraints etc.) and emerging requirements (an ageing population, regional inequalities etc.), taking advantage of the development of information and communication technologies. Research should spark and underpin the development of innovations in urban engineering. Challenges to be taken up include civil engineering in dense urban environments, coordinating nationwide networks with their micro-local counterparts, network interoperability, more flexible standards and "customisation" for better responses to users' needs, adapting networks to hazards or improving their resilience to short-term disruption (breakdowns etc.) or medium- to long-term evolution (shrinking cities, future generations, climate change).

Smart cities, new practices and innovative services

Information and communication technologies have been increasing the efficiency and productivity of urban services for a long time. The notion of the ***smart city*** goes further by contemplating different organisational models for these services that are more decentralised, more responsive and more immediate. Considerable changes could be made with regard to implementation, operation, economics, engineering and logistics as well as regulation, behaviours and governance. For example, smart cities could be key enablers in the transition towards more energy-efficient urban activities. They leave open the question of regional inequalities in old, less-connected districts with no real return on investment for digital companies. In addition, information and communication

technologies enable the emergence of **new services**, for example in freight transport and mobility, and create new channels for public information and action that may spur citizens into helping to provide new services (collaborative economy) and changing their practices in many areas (consumption, mobility, participation in governance etc.). Truly multidisciplinary research is expected on these issues, identifying the impacts of a shift towards the **digital city** on the **practices** of urban dwellers and on the **urban metabolism**.

B.7 – Research to be conducted in response to the "Information and communication society" challenge

Introduction

The "Information and communication society" challenge calls for basic and applied research in digital sciences and technologies. The cross-disciplinary nature of this research also makes it relevant in a more application-based and interdisciplinary approach, to respond to all the Work Programme challenges.

Digital sciences and technologies are at the heart of major economic, social and human issues. Integrated circuits and processors have become omnipresent – they can now be found in a wide range of utility, domestic and leisure equipment. Connectivity between these devices and telecommunications networks, and ultimately the Internet, has become or is becoming the norm. The critical role played by information systems in the smooth operation of major public infrastructure (transport, water, energy etc.), companies and institutions raises questions over security, safety and sovereignty. The analysis of data, whether or not it is generated by these systems, for diagnostic purposes, decision support and task automation is growing rapidly. Expertise in hardware, software and network technology is thus more strategically important than ever, for both our autonomy and our competitiveness. Several digital technologies contribute to advances in science: the processing of huge volumes of data produced by scientific observation in biology, physics, astrophysics etc., high-performance computing used for simulation in most disciplines, connected objects for scientific observation etc.

In addition, the accelerated convergence between the digital and physical worlds implies the development of techniques for human-machine interaction using a multi-sensory approach. It also calls for research focusing on the development of autonomous, highly-interactive robotics for professional, domestic and service purposes.

Progress in digital science and technology is also dependent on progress in micro- and nanoelectronics, IT, mathematics, automation, signal processing etc. To cover the full range of research fields and applications, researchers in all disciplines need to foster close cooperation in all sectors of activity.

The "Information and communication society" challenge thus has two priorities: exploring how digital technology can serve society and designing and developing tomorrow's digital technologies by evolving concepts, methods and tools. It includes seven themes:

Theme 7.1: Foundations of digital technology

Theme 7.2: Software sciences and technologies

Theme 7.3: Interaction, robotics and artificial intelligence

Theme 7.4: Data, knowledge, big data, multimedia content and artificial intelligence

Theme 7.5: High-performance computer simulation for understanding, optimisation and decision making

Theme 7.6: High-performance communication infrastructure (network, computing and storage)

Theme 7.7: Micro- and nanotechnologies for information and communication processing

Lastly, in the context of the FranceIA initiative and the future Flagship soon to be launched by the European Commission, the "Information and communication society" challenge highlights two scientific fields: artificial intelligence (AI) and quantum technologies.

The need to process huge volumes of data (images, text, music etc.) produced by human activity and scientific observation, the availability of data through Internet connectivity and the benefits of its commercial exploitation have been major factors in the renewal of Artificial Intelligence, and particularly in the development of machine learning and the emergence of data analytics. The impacts on society, in terms of employment or the transformation of certain occupations, for example, have prompted multidisciplinary discussions on the ethical, legal and societal consequences and on the scientific issues, and have led to the development of new research programmes and avenues[5]. Within the "Information and communication society" challenge, the problems of artificial intelligence are found explicitly under themes 7-3, "*Interaction, robotics and artificial intelligence*", and 7-4, "*Data, knowledge, big data, multimedia content and artificial intelligence".*

Quantum technologies constitute a set of disruptive technologies that relate firstly to information processing, communication and security and secondly to the production of extremely accurate measurements and sensors. In return, these new technologies stimulate basic studies that were previously inaccessible. We are seeing massive investment in quantum technologies all over the world. The technological exploitation of concepts from quantum mechanics, such as superposition or the entanglement of micro- and nanometric objects and photons, promises radical changes in the power of future computers, far exceeding the most advanced current models and ensuring unbreakable security for communications. New sensors can be designed for prospecting for underground wealth, improving GPS or analysing individual biomolecules.

These developments promise a considerable economic and societal impact for quantum technologies. Basic knowledge of quantum mechanics must be broadened through research and technologies and innovations must be developed for these technologies to reach full maturity.

Quantum technologies are addressed in the "Information and communication society" challenge in particular, but they are also relevant to other challenges and the non-challenge section. Projects addressing quantum technology will be evaluated by a specific panel.

B.7 – Theme 1: Foundations of digital technology

This theme is geared towards basic research projects striving for excellence and breakthroughs in the fields of IT, mathematics and the science and engineering of systems and communications. Basic research is strongly encouraged, as it drives progress that will subsequently spark and fuel application-oriented research. The basic research expected for this theme must: i) be clearly relevant to the "Information and communication society" challenge and ii) not relate **explicitly** to another theme in the challenge. This theme supplements the "Mathematics" theme in the non-challenge

section (see section B.10 – Theme 1).

The following is a non-exhaustive guide to the fields in which basic research projects are expected:

- ***Mathematics and interactions***: fundamental aspects of mathematical models and methods in a broad sense, in connection with the challenges of digital technology (including partial differential equations, control, optimisation, numerical analysis, probability and statistical methodologies as well as certain aspects of fundamental mathematics, such as number theory);
- ***Theoretical computer science***: fundamental aspects including algorithmics, logic, computability, decidability, combinatorics, formal methods, semantics, game theory, quantum computing, the foundations of artificial intelligence and machine learning;
- ***Automation***: fundamental aspects of control and observation, estimation and identification, systems theory and modelling and control, optimisation and learning;
- ***Signal processing***: fundamental aspects of statistical signal processing and detection/estimation, analysis and representation, information theory, learning and optimisation.

Collaborative projects combining several fields in computing, systems science and engineering, communications and mathematics related to the key aspects of the "Information and communication society" challenge, are also expected for this theme.

Methodological projects including, but not limited to, the development of parsimonious, incremental, distributed and multimodal graph models and co-design models with no direct application in the other themes of the "Information and communication society" challenge are expected for this theme.

Mathematical, statistical and computer modelling has become essential in many application areas in understanding systemic functioning and networks of interaction. Projects that will develop new conceptual approaches and methods (computing, automation, signal processing, mathematics, statistics) to model these systems are also expected under this theme.

Conversely, projects that emphasise application areas but do not target methodological developments must be submitted under the corresponding societal challenges.

Problems relating to biology and health should be submitted under the inter-challenge theme B.11 Theme 1 (see the inter-challenge section).

B.7 – Theme 2: Software sciences and technologies

Software is a key component of digital systems, providing them with power, intelligence, flexibility, agility and durability. It enables potentially limitless sophistication and versatility, although it engenders a level of complexity that needs to be controlled through structure and raising the level of abstraction, in terms of both design (languages, programming paradigms, software architectures) and execution (middleware and software platforms). In addition, the production of reliable software, in terms of safety and security, is costly, hence the importance of architectural principles ensuring these properties and of proven, automated design, validation and debugging

methods.

This theme supports basic and applied research in software technologies, relating to software design and validation and the software platforms required for execution in all application areas (from connected objects to large-scale systems).

The major topics in this theme are the following:

- ***Software execution platforms*** meeting specific requirements (real time, performance, security, safety, distributed computing etc.): operating systems, virtualisation tools, embedded systems, memory management, distributed execution, specific middleware for different architectural principles (parallel computing, distributed computing, real time etc.) and certain types of application, including connected objects (protocols, energy savings, security).
- ***Software design methods and tools***: programming and specification languages, compilation optimised for centralised or parallel architectures, specific computing models for parallel computing, distributed computing, mobility, security and embedded, real-time and cyber-physical systems, software engineering, design methods (model-based design, agile methods etc.), software architectures and components.
- ***Software validation***: methods and tools for analysing, verifying and proving the properties (security and safety) of algorithms and programs, verifying and optimising their quantitative properties (time, memory, energy etc.), testing, debugging, software and hardware simulation methods, virtual prototyping.

Proposals related to execution platforms (at different scales) are of particular interest.

The attention of project sponsors is drawn to the need to position their project in relation to other national and European calls in the field and with regard to standardisation groups and alliances where relevant.

B.7 – Theme 3: Interaction, robotics and artificial intelligence

The accelerated convergence of the digital and physical worlds in all their forms with our everyday environment epitomises a major technological shift and implies especially the need to develop 1) useful, usable and even pleasant interaction techniques tailored to the attributes of human interaction and to different interaction contexts and 2) autonomous, highly-interactive robotics for industrial (the subject of theme 1 of the "Stimulate industrial renewal" challenge), domestic and service purposes. This theme covers artificial intelligence research on two major topics:

- ***Human-machine interaction***: Interaction depends on multi-sensory interfaces combining contact, gestures, movement, speech, vision, eye sensors, context capture and detecting the user's mental and physical state.

It can thus be based on wearable computing techniques or technologies to augment or extend human ability (smart glasses and watches, implants or BCIs, for example). Research is also expected in human-machine interaction that that is tailored both to the attributes of human interaction and to the context of interaction and use: graphical interaction, including analytical visualisation (in conjunction with theme 4 of the "Information and communication society" challenge), but also interaction beyond the keyboard-mouse-screen or touch-screen: augmented reality; virtual reality; multimodal, gestural, tangible, mobile and physical interaction; interaction with augmented and

connected physical objects (Internet of Interactive Things in conjunction with theme 6 of the challenge); multimodal interfaces and deformable interfaces. This includes both research into interaction techniques and interaction engineering to define design, development and evaluation tools. This research will need to incorporate a wide range of interaction contexts and diverse users (age, mobility, sensory and cognitive disabilities) from the design phase and consider the interdisciplinary dimension of human-machine interaction throughout the process of creating future digital products.

The research expected also relates to human-machine communication, including the implementation of natural human-machine dialogue systems in terms of both understanding and generating language (mono- or multimodal, including oral or written natural language), knowledge representation and inference, modelling and automating intelligent behaviour (including models of reasoning about mental states and the planning of communicative acts, possibly in combination with "physical" acts). From the perspective of cognitive agents, and in connection with the "autonomous and interactive robotics" subtheme, proposals at the intersection between communicative cognitive robotics and intuitive human-robot interactions, addressing issues central to artificial intelligence, are encouraged.

• ***Autonomous and interactive robotics***: Robotics presents a series of highly diverse research questions related to robot design and control, scene perception and interpretation, the planning and execution of movement and handling actions, learning and human-robot interaction. These questions arise in many application contexts with a very broad societal impact, such as manufacturing processes (the focus of theme 1 of the "Stimulate industrial renewal" challenge), hostile environments and assistance services. Robots can take a variety of forms adapted to their industrial or consumer purposes, ranging from humanoids to drones and including off-road mobile robots, telepresence robots, exoskeletons and manufacturing robots (see theme 1 of the "Stimulate industrial renewal" challenge). Innovative projects are encouraged on issues relating to operational autonomy, decision-making abilities in conjunction with artificial intelligence, action planning and decision-making (independently or in conjunction with humans), multimodal physical and/or cognitive human-robot interaction, cognitive architectures and learning capabilities, all of which are significant topics that also open up avenues for interdisciplinary research with the life sciences, social sciences and humanities, including cognitive science.

Projects incorporating ethical aspects are encouraged, especially if they involve interdisciplinary approaches. This covers research ethics in the context of responsible research, the ethics of use in terms of compliance with ethical rules when implementing technologies in application contexts and social interactions, and the ethics of systems, i.e. the inclusion of rules and ethical behaviours in algorithms (artificial moral agents).

B.7 – Theme 4: Data, knowledge, big data, multimedia content and artificial intelligence

This theme is organised into three topics: defining and studying processes and technologies for use in analysing, linking and thinking about data; processing big data and, lastly, processing multimedia content. The expected proposals will contribute to the development of all the communities that rely on data science.

Proposals may fall clearly within the field of information and communication science

and technology, such as image, video, speech and natural language processing, or in an interdisciplinary context involving IT experts, statisticians or specialists in the digital humanities. They should propose, design and analyse methods to store, index, annotate and analyse data and content in order to extract knowledge.

The major topics in this theme are the following:

• ***From data to knowledge*****:** This theme relates to processes and technologies for extracting knowledge from data, especially through automatic learning, semantic analysis (structured and unstructured data, images, videos etc.), modelling, knowledge aggregation and reasoning. These processes implement algorithms and solutions (particularly for deep learning) that involve complex processing chains to obtain high-added-value information products (rules, behaviours, prototypes, patterns, detection of rare events etc.) that increase the abilities or decision-making capacity of users (experts, decision-makers or students).

A key point is the production of verified knowledge (by ensuring that processes are robust even when faced with incomplete, uncertain or inaccurate data, by assessing the confidence to be placed in the findings and by developing predictive models in based on available knowledge) and verifiable knowledge (by proposing processes that encourage transparent reasoning and analyses that improve understanding).

• ***Big data*****:** Processing large volumes of data has become a strategic field of major economic and societal importance, bringing out new economic concepts. The main challenges relate to scaling up, complexity, heterogeneity, speed, validity, veracity, intellectual property, data protection and confidentiality.

This theme is looking for proposals concerning all or part of the data value chain: collection (including real-time flows), organisation and processing in distributed databases or data lakes, storage, indexing, semantic analysis and automatic ontology construction, integration and cross-referencing of heterogeneous data sources, search processes for sourcing significant additional open data, automatic generation of additional variables or representations (feature engineering, deep learning), search engines for structured and unstructured data and processing parallel requests, factoring in personal data protection and security for data and processing, data mining and analysis algorithms for mass structured or unstructured multimedia data, retrieval and visualisation mechanisms suited to large volumes or to networked data.

The proposed techniques may make use of existing tools or suggest innovative contributions to the main free or proprietary software libraries. The data processing chains will showcase the mechanisms for extracting and structuring knowledge in application areas with real implications (web, banking/insurance, distribution, energy, transport, health, connected objects, environment, home automation, agriculture, security etc.). The availability of significant data sets should be specified in the proposal, with a timetable for their availability and access conditions.

• ***Processing multimedia content***: this section addresses the entire digital content chain: creation, capture, production, editing, access, analysis, exchange, preservation etc. It covers content for all media types: cinema, radio, TV, web, video games as well as the multimedia and multilingual aspects of all documents. The projects will aim to support changing practices – collaborative, collective and individual – associated with the creative, cultural and publishing industries and to address new ways of writing, narrating, producing, disseminating and enhancing digital content, with the associated

problems of usage and exploitation rights (watermarking and traceability). It is important to design technological solutions suited to new trends in content consumption in terms of mobility, multi-screen usage, browsing and dynamic discovery which take into account the diversity of users. Proposals could be based on existing data sets (such as the corpus provided by INA at http://dataset.ina.fr) to develop their research. Projects coordinated by a highly interdisciplinary consortium of ICT/SSH researchers should be submitted under B.11 Theme 4 (see the inter-challenge section).

Basic research projects on processing 2D/3D images, video, speech, music and audio, as well as natural language processing (NLP) and sign language, are expected in this theme.

B.7 – Theme 5: Intensive digital simulation for understanding, optimisation and decision making

Despite huge advances in scientific computing and digital simulation over the past thirty years, it is obvious that scientific and technical barriers still remain that prevent real advantage being taken of the full potential of computers and algorithms in most fields of activity. With theme 6 of the "Information and communication society" challenge, ANR is focusing more specifically on the following three objectives:

- Satisfy the need for **exceptional high-performance computing** (in conjunction with the exascale challenge, for example) and also pragmatically encourage the necessary transitions from existing disciplines to the future generations of computers,
- Encourage and stimulate the "democratisation" of access to algorithms, thereby allowing new players (SME and middle-market companies, for example) to **take advantage of high-performance computing** (problem of increasingly sophisticated specialist libraries on computing architectures at affordable costs),
- **Enable disciplinary breakthroughs** to improve performance or cost by orders of magnitude through intelligent new ways of exploiting future high-performance computers (mixed architectures, family of quantum computers).

A great many fields in science (genomics, environment, climate, universe sciences, physical sciences, sociology etc.) and technology (energy, transport, pharmaceuticals, manufacturing, finance etc.) are already exploiting the possibilities of high-performance computing and the resulting competitive advantages. However, effective scientific or socioeconomic progress varies from one field to the next, mainly because computer architectures evolve principally under the influence of economic sectors whose needs and criteria can sometimes be very specific. Considerable efforts must be made in the fields of algorithms and mathematics to take real advantage of architectures that are constantly moving forward.

Proposals are thus expected that involve disciplinary experts, computer scientists, analysts, mathematicians, statisticians, data scientists etc. and contribute to the emergence of a community with the ability to make progress on the following problems (non-exhaustive list):

1. Legacy software will reap no benefit from the arrival of exascale computing without significant or even disruptive development in

libraries and programming paradigms: obstacles can be identified relating to the suitability of scientific high-performance computing libraries for future architectures, the development and introduction of runtime systems in complex simulations, the need for in situ visualisation, fault tolerance etc.,

2. Highly demanding engineering challenges require significant advances in **numerical and algorithmic methods**: obstacles can be identified relating to software (time-space parallelism, reductions in data transfers, construction and use of so-called surrogate models, etc.) and also to hardware (use of NVM memory, energy consumption etc.),
3. Known engineering projects are not deployed quickly enough in certain sectors, nor are they **implemented** in the most **effective** way: barriers still remain that prevent multi-scale, multidisciplinary analyses already suggested several years ago from taking full advantage of suitable solvers, strong and weak coupling formulations, reverse approaches, optimisation methods, uncertainty quantification etc.
4. Innovative computing architectures could provide **breakthroughs in several hard problems** if certain technological barriers were removed; more generically, there are multiple issues in what is known as the post-Moore era, from architectures and programming models to applications.
5. Approaches that **combine modelling through digital simulation with modelling through data** add to the expectations, for example when computation has to supplement or enrich a lack of data collected elsewhere; the barriers then relate to the data flow, including managing the **data deluge**, new paradigms, algorithms, methods and tools.

Proposals should be in line with the initiatives in European projects, especially those related to the European PPP ETP4HPC platform and PRACE HPC infrastructure.

Projects relating exclusively to complex system engineering should be submitted under the "Stimulate industrial renewal" section.

Projects relating to applications associated with quantum computers should be submitted to the "Quantum technology" evaluation panel.

Projects relating to mathematics and numerical schemes not associated with high-performance computing issues should be submitted under theme 7-1 of this challenge.

Projects relating to the interaction between simulation results and humans should ideally be placed under theme 7-3 of this challenge.

B.7 – Theme 6: High-performance communication infrastructure (network, computing and storage)

Communication, processing and storage infrastructure is fundamental to the workings of our digital society: it plays a key role in fields as varied and vital as knowledge sharing, the emergence of smart cities and smart transport, the widespread use of electronic transactions, energy optimisation and big data processing in many fields (industry, environment, healthcare etc.). The prospect of a proliferation of connected objects leading to a huge increase in the potential for innovative applications will require new paradigms for communicating, processing and storing (potentially big)

data.

Given the diversity of applications and the speed of change, infrastructure must be capable of achieving high levels of performance and efficiency, while remaining open and agile enough to adapt both to scale-up issues and to meeting the diverse, dynamic requirements of applications.

To meet these objectives, research projects are expected on the following major themes:

- **High-speed communications infrastructure**: Current approaches in optics as well as radio are nearing the theoretical limits of transmission capacity and breakthroughs are necessary to absorb sustained growth in bandwidth demand in the long term. This increase in system capacity must be reconciled with energy efficiency, elasticity, flexibility and programmability.
- **Networks of objects**: The prospect of tens of billions of connected objects requires significant changes to networks. Systems will need to dynamically incorporate increasingly distributed and heterogeneous equipment and devices, requiring the use of self-organisation approaches. Network architecture and interfaces must be redesigned to meet demanding requirements: a massive increase in the capacity of the control plan to process sporadic transmissions from a large number of objects, a significant change in traffic characteristics with the proliferation of transmissions of short bursts of data, very restricted power consumption of objects with limited power reserves. At the same time, cost control, reliability, responsiveness and latency all have to be monitored.
- **Major infrastructure architecture (HPC, cloud, data centres)**: The emergence of the Internet of Things, moving content and processing to the network periphery and the standardised use of multi-core processors are forcing a global redesign of infrastructure architecture and the location of functions and data. Centralised versus distributed approaches must be reconsidered in this context.

  HPC infrastructure must evolve to meet growing needs for data processing and storage. This will include improved performance from massively parallel computing nodes and the performance of the interconnection networks between nodes. Energy efficiency, reliability and fault tolerance must be built into solutions.

  Virtualisation enables many network functions to be hosted on cloud servers instead of dedicated telecoms equipment. Conversely, there is a growing need to locate content and applications close to users on the periphery of networks, to reduce latency for example. These new architectures require research on the best compromise between centralised and distributed approaches and on the dynamic optimisation of function placement and orchestration.
- **Management, control, optimisation, supervision and programming of networks, the cloud, systems and services**

  Infrastructure complexity combined with the requirement for agility, resource optimisation and demanding service level agreements mean providing infrastructure with increased operational intelligence and a high level of automation. Operating system software encompassing network, storage and computing resources with end-to-end management must be developed.

  A software-defined networking layer must connect and program different

applications and hardware dynamically to create end-to-end virtual network slices optimised for different purposes. This call places particular emphasis on projects that use machine learning techniques to optimise infrastructure and projects incorporating research into end-to-end, multi-layer security by design.

The infrastructure of the future should also be capable of supporting the creation and optimisation of innovative services that are highly dynamic. The aim is to design operating systems that enable services to be created and orchestrated quickly, automatically and intuitively. They must be able to build a knowledge map (which could be based on artificial intelligence approaches) and contextualise service delivery to match the user context as much as possible. Infrastructure should natively incorporate decentralised, secured transactions (standardisation of the block chain paradigm), making a multitude of local markets and new economic models possible.

B.7 – Theme 7: Micro- and nanotechnologies for information and communication processing

This theme covers the key generic technologies of electronics and photonics for information and communication, the question of integrating devices into systems and the exploration of new paradigms, possibly based on quantum properties or bio-inspiration. All projects should address well-identified scientific and technological hurdles in the field of ICT and seek to demonstrate either quantifiable improvements in performance or breakthroughs compared with existing knowledge. They must fit into one of the three areas described below.

Projects mainly or exclusively targeting theoretical or numerical approaches (simulation and/or design of components, materials, processes, complex systems) are entirely legitimate, but so are generic methodologies (design, testing, metrology), reliability studies, the advanced characterisation of materials or the performance of nanodevices/basic components. They will be listed in one of the following areas, in line with the subjects discussed.

• *Micro- and nanostructured materials for incorporating into components: development-manufacturing-processes:*

This topic covers the basic technological building block essential for future innovations, made up of micro- and nanostructured materials, ranging from semiconductors (IV-IV, III-V, II-VI/nitrides) or other materials for electronics and photonics to materials for spintronics. It also covers the manufacturing processes of artificial materials and metamaterials.

This theme specifically concerns the development of materials and basic studies of nanometric objects with a view to integrating them into components and devices.

Projects involving research into solid materials and their properties fall within the scope of theme 3.2 of the “Stimulate industrial renewal” challenge, whereas projects focused on materials for flexible electronics come under theme 3.5 of the “Stimulate industrial renewal” challenge if possibilities for integration are not explored.

• *Basic components and devices:*

This theme concerns projects that aim to achieve basic functions for micro- and nanoelectronics, spintronics and quantum and non-linear optics, near-field optics,

wavefront processing, the millimetre and THz domains, plasmonics, nanophotonics and organic/flexible electronics and optoelectronics. It also covers alternative methods such as quantum and neuromorphic technologies.

For projects that focus particularly on micro- and nano-scale integration, objectives such as the development of optical sources, optical fibres and new components for optics may also be considered in this theme.

- ***Waves – Architectures – Integration – Circuits – Systems:***

Projects under this theme will deal with the issue of integrating devices or components: 3D integration, heterogeneous integration, alternative architectures (bio-inspired, neuromorphic etc.).

They may address a hurdle (or problem) associated with photodetection and the associated imagers, architectures and technologies related to the integration of optics into systems, micro- and nanosystems, circuits and sensors as connected, smart and/or autonomous objects.

The projects could also address the optimisation of systems for information processing or for communications (optics, RF etc.).

Projects relating to sensors should be submitted under theme 7.6 of the "Information and communication society" challenge if the aim is to create a networked sensor infrastructure, or theme 3.6 of the "Stimulate industrial renewal" challenge if the research objectives are the transduction or study of physical, chemical and biological properties of micro- and nanodetectors etc).

Projects in this theme will be monodisciplinary, multidisciplinary or interdisciplinary. They may propose experimental and/or instrumental developments, adopt an integrative approach by encouraging the transfer of technology to business or opt for more basic research that addresses challenges in information and communication science and technology. Digital simulation, modelling and theory may contribute to mainly experimental projects or be the focus of specific projects.

Sponsors of projects in the field of the European "Graphene" or "Human Brain Project" FET Flagship initiatives and projects addressing the issues of the emerging European initiative on quantum technologies are invited to present the potential links with these initiatives.

B.8 - Research to be conducted in response to the "Innovative, inclusive and adaptive societies" challenge

Introduction

As recommended by the SNR, MENESR, DGRI and the ATHENA Alliance, the guidelines for the "Innovative, inclusive and adaptive societies" challenge take account of the **vast spectrum of disciplinary fields grouped under the SSH banner** (without exclusions) as listed in the National Strategy for Research and Innovation classification (SHS1 to 6: markets and organisations/standards, institutions and social behaviours/space, environment and societies/human spirit, language, education/languages, literature, arts, philosophy, culture/ancient and contemporary worlds) and the European Research Council classification (SH 1 to 6: individuals, institutions and markets/institutions, values, beliefs and behaviour/environment, space and population/the human mind and its complexity/cultures and cultural production/the study of the human past).

Based on the recommendations of the challenge's scientific advisory panel, and informed by the above guidelines, the major themes have been maintained overall but partially rethought and enriched for the 2018 edition. They are broken down into six themes.

Under these themes and the inter-challenge themes, the "Innovative, inclusive and adaptive societies" challenge is open to both basic and applied research. All methods (quantitative, qualitative, qualitative-quantitative etc.), all techniques and all approaches based on direct investigation or on second-hand data sources are welcome. Special attention will be given to research into **gender** and all its theoretical or themed dimensions in the field of SSH: questions of ethics, identity, social representation and parity in both science subjects and in research institutions.

It is expected that methodological approaches will be explained and applied to theoretical questioning. Wherever possible, researchers are encouraged to draw on large databases, archives and longitudinal studies from very large research infrastructure (TGRI) and databases of European consortia (like DARIAH). Within the limits of the financial resources available, Challenge 8 may help to **fund surveys** or **constitute corpora** (texts, images, oral archives) on three conditions: 1) that they be associated with a real **research project** ; 2) that **free access** to the data is provided and 3) that a mechanism exists for **preserving** the data for the long term. Projects relying on the processing of personal data must pay special attention to protecting the data, and this point will be considered in the evaluation.

B.8 – Theme 1: Social innovation and progress

This theme is designed to accommodate research projects on themes focusing on the innovation process itself that are likely to shed light on its social, economic, cultural and organisational dimensions. *(The "Efficient resource management and adaptation to climate change", "Stimulate industrial renewal" and "Mobility and sustainable urban systems" challenges are available for projects that deal primarily with the technical aspects of these fields.)*

This theme is divided into four broad topics:

- Theories and practices of innovative design;
- Innovation and its relation to risk taking;
- Social movements around innovation;
- Adoption models and forms of appropriation.

The theme is about using innovation to address social creativity and its preconditions (urgent needs or prosperity), processes, players, experiences and modalities (technical, cultural, ideological and economic pathways of innovation). The constraints weighing on innovation must be considered, as must the relationship to opportunity, the creation of value through breakthroughs, the emerging rules of innovative design, the desire to innovate and its imaginative worlds and representations. Researchers are invited to explore innovation trajectories and the fields in question (housing, cities, transport, industry, economics, digital practices, socio-cultural behaviours and representations etc.). Innovation policies, legislative and regulatory frameworks (intellectual property, patents, personal data protection etc.) and lastly the standards and mechanisms of expertise should be considered. The relationship to risk taking also opens up research into neurocognition, investment theory and entrepreneurship theory.

Innovation supported and/or driven by **social movements**, value systems and conditions (economic, political, social, cultural, academic, religious, family, demographic etc.) may be addressed, with no limits on historical period or geographical and cultural breakdown. Attention should also be given to innovative social movements in all fields (law, health, food, media, beliefs, education, economics etc.) and the processes by which innovations are generated and/or disseminated. Who are the social drivers of innovation? How are they organised? With what resources? For what social or cultural impact? Demographic, family and social behaviours may also be addressed, including their vectors, their economic and social effects and the extensive debates that cause them to evolve.

Particular consideration should be given to modes of appropriation, resistance, the plurality of knowledge and expertise and the forms of interaction between innovation supporters and societies, without forgetting gender relationships. Topics for consideration include the sources and impacts of innovation in terms of **persuasion** or **influence** from an open perspective (psychological, sociological, philosophical, political, economic etc.), including rhetoric and behavioural science. The new paradigms of innovation in globalisation and their impact on societies can also be considered.

B.8 – Theme 2: Inequality, discrimination, migration and radicalisation

This second theme encourages projects addressing the question of **inequality, discrimination and migration.** Added to this is a section on **extreme radicalisation.**

It is broken down into five major analytical topics:

- Socioeconomic inequalities, inequalities between nations;
- New socioeconomic indicators for well-being or integration;
- Discrimination and diversity;
- International migration: migration factors in migrant asylum and reception policies;
- Violent radicalisation.

The scientific treatment of inequalities (except those relating to health, which are dealt with in inter-challenge theme 8) could consider their subjective perception in parallel with their objective reality. This involves studying logics of withdrawal and exclusion in their various forms (economic or social) and what they reveal in terms of **strategies** (social **mobility** or **recognition**, for example) and **dynamics** (networks, individual positioning and also segregation). Public policies on inequalities may also be examined, together with international relations.

Research into inequalities may extend to the study of "development", "well-being" and "integration" **indicators**. The very construction of these indicators should be analysed and evaluated, taking the new approaches, theories or methodological frameworks that inspire these **measurements** into account.

Building on the theory and, up to a certain point, the methodology of studying inequalities, theme 2 will also be open to projects dealing with **discrimination** and its forms, sources and criteria. Projects focusing on subjective perceptions and effects on social recognition, employment, training, housing and services can also be submitted.

A field as vast as this can be an opportunity to apply appropriate **methods** (investigating archive sources, direct observation, study of inter-individual relations or of unusual social environments etc.) to understand individual prejudices or statistical discrimination (affecting broader social categories), with the possibility of involving private entities or government in the research. How do these entities use the methodological guide published in 2012 by the CNIL and the ombudsman on measuring diversity?

The projects could also relate to **theories of integration** and its correlates (economic integration, social and cultural **inclusion**) and their impact on collective **allegiances** (affiliations, identification). Their central focus will be the legal requirements imposed on individuals and a critical analysis of the scope and limitations of **instruments to measure** their "integration", a notion that deserves to be consigned to history.

The theme of **migrations** could attract research on the causes, modalities, processes and impacts (on the migrants and on the societies they have joined and left behind), spatial and cultural extension (remigration, historical and even prehistoric movements etc.), whilst investigating the potentially multiple legal frameworks governing these mobilities, especially in terms of cultural diversity.

The current migration situation deserves further investigation, focused especially on asylum and the crisis point it has reached throughout Europe and worldwide since 2015. This research could also be enriched by national or comparative analyses of the historical and legal backgrounds of restricted mobilities. Research could focus on the frameworks and conditions of expatriation, migration routes, types of migration, the encounter between migrants, asylum seekers and host societies, without excluding the study of emotional reactions that tip the balance towards the rejection of these populations or towards expressions of compassion and solidarity.

Projects relating to extreme violence and violent **radicalisation** may also fall under this theme (the security aspects are shared with the "Freedom and security of Europe, its citizens and its residents" challenge). Proposals from a variety of disciplinary fields that analyse the triggers, reasons, forms of socialisation or desocialisation, routes, networks, ideological frameworks and processes of violent radicalisation relating mainly (but not solely) to terrorism or religious or political totalitarian thinking are expected. Methods

for managing or **preventing** radicalisation, **geopolitical** contexts, which include all kinds of transnational networks (social networks, terrorist cells etc.), and global **conditions** should also be considered. Special attention should be paid to exits from violence and to conflict resolution, including peace studies.

B.8 – Theme 3: Changes in labour and employment

Employment and **work** draw on approaches from the broad spectrum of disciplines covered by this theme, which is also associated with organisational change.

It includes three major themes:

- Labour and employment market and transformation of companies;
- Labour and society;
- The challenge of professional equality.

Projects may relate to the labour and employment **market**, professional **career paths**, **changes in employment** and in **public policies**, from a critical perspective associated with changing **contexts** (including the development of digital technology), **changes in companies** and their interactions with their **environment** and alterations in the links between employment and the management of social risks.

Projects may develop the analysis of labour **regulation** methods (law, social responsibility, soft law) and **changes in companies** (in terms of **governance**, **objectives**, **organisation**, internal and external structure, networks etc.).

The relationship to work itself could be a subject of analysis: its **quality**, individuals' relationships to their work and the place it occupies in society remain central concerns for the sciences, at a time of (large-scale) division and (individual) fragmentation of professional practices and management methods.

Research could cover the **evolution of work**, its **measurement** (duration, performance, intensity) and **evaluation**, remuneration, management, risks, quality of work and the ways people commit to it personally and emotionally, leading on to the **parameters of health at work** (which can also be dealt with under the "public health" theme shared with the "Life, health and well-being" challenge, provided that healthcare is the primary research topic).

The challenge of professional inequalities (equality of time, gender, social pressure and performance) offers research projects a fertile starting point for the broader study of the place of work in society. Lastly, globalisation and its impact on employment and labour could also be a subject for research, taking in new digital companies and artificial intelligence, or the current situation of phenomena such as robotisation, automation, "uberisation" and the development of cyber-surveillance at work. Societal issues and debates surrounding the loss of pre-digital jobs and the end of work could be addressed, in conjunction with international geostrategic comparisons (and also with the "Stimulate industrial renewal" challenge and its "factory of the future" theme for industrial perspectives).

B.8 – Theme 4: Lifelong cognitive skills, education and training

At the heart of this theme lie the questions of education, training and learning as redefined by the cognitive capacities, social practices and social and developmental changes in individuals throughout their life.

It is structured around four theoretical and methodological development areas:

- Cognitive capacities at different ages in life;
- Educational innovations and practices;
- Combating educational failure;
- Changes in higher education.

Research will investigate learning **conditions** and **techniques**, which evolve throughout life, and means of appropriating the **cultural objects** that give form and meaning to psychological and social life. The entire field of the social sciences, humanities and cognitive sciences (from neuroscience and psycholinguistics to sociology and history) is invited to propose research projects that deal with **learning processes** and models and the methods and conditions for **forming knowledge** of all types (practical, linguistic, theoretical and disciplinary). **Sources** of knowledge and **access** to them (especially through digital technologies) are also included in this theme. Open methodological approaches can cover all aspects of learning, including **learning deficiencies, disability** and **ageing**, together with approaches based on cognitive ergonomics.

Research will examine not only tools but also educational innovations, including (but not only) in a context of school or university inequalities and of growing needs for lifelong learning. Research is expected on the function of the teacher, how the role is exercised, **relations between teachers and pupils/students**, types of **teaching methods** and the skills acquired. Experimental or non-experimental methods to assess their **effectiveness** (and their **transposition** to concrete situations, i.e. in practical teaching contexts) fall within this theoretical scope.

Researchers could adopt a learning engineering approach to developing, testing and validating **educational tools (MOOC, SPOC etc.), both in the classroom and for e-learning, suited to diverse audiences** (age, experience, previous knowledge, social environment, economic models etc.), without forgetting learning analytics and other digital learning records at school and university. **Learning with digital technology** must provide all the benefits of advances in digital techniques, information and communication sciences and cognition. How can we define smart learning pathways tailored to the needs of individual learners? How can we track the individual progress of each learner? How can we assess proposed mediated learning solutions? How can we cater for individuals suffering from learning difficulties or deficits? What are the underlying risks of exploiting data? Researchers could also look into **modelling** learning and **socialisation**.

One section of this theme extends this research to **combating failure** at all educational levels based on an analysis of its **psychological factors** (motivations, mental or emotional reactions) and social factors (influence of institutions, gender, collective representations, family pressure etc.). Projects may focus on the study of **early schooling**, **dropouts** and **changes of direction**, considering how to develop the various forms of intelligence and social and psychological skills. It should be possible to use this as a basis for assessing the specific features of the French **school, university and careers guidance systems** (compared with other socio-educational and cultural realities) and questioning the disaffection with learning and the connection with employability, socialisation and integration.

Projects on **changes in higher education and research** that relate to any location,

institution or organisation where they take place will also be considered. This area remains underexplored by the social sciences and humanities despite increased competition, the many, regular reforms and ever-increasing pressure (towards interdisciplinarity and internationalisation) whose forms, manifestations and consequences need to be better understood.

B.8 – Theme 5: Cultures, creation and heritage

This theme covers the study of cultures, creation and heritage and its quest to shed light on the diversity of societies, the transformations of cultural, economic and political practices and mechanisms of integration, adaptation and innovation.

It brings together four topics:

- Interdisciplinary approaches to cultures and religion;
- Prehistory and history of cultural and cognitive phenomena, the future of languages;
- Creation, works and creators;
- Heritage transformations and cultural policies.

All the social sciences and humanities are invited to submit original research proposals relating to the diversity of societies and ways in which they emerge. Research should focus especially on the cognitive skills that explain the appearance of sociocultural behaviours (languages, beliefs, social structures etc.) or, from a theoretical viewpoint, social and communication practices and processes of change. Cultural, linguistic, biological and/or environmental approaches are also welcome.

On this long diachronic scale, taking a comparative approach, a section is set aside for **human populations** through their evolution up to the present day and their variability in terms of habitat, climate, language and other key variables.

The dissemination and transformation of cultures (material, written, oral, auditory or visual), artistic practices, cultural, philosophical or literary styles and works and the circulation of concepts and ideas will be addressed **from prehistory to modern times, spanning all areas of culture** at the individual and group levels. All disciplinary fields are covered, including **global studies**, **cultural studies and environmental humanities** as well as, if necessary, the relations between knowledge, science and literature.

Religion in all its diversity will also be addressed here: formation, transmission and use of sacred texts, rites and beliefs, revivals and conversions, networks of religious or educational institutions, relations between sacred and secular art, the place of religion in the public arena, questions of secularism, the role of religious identity as a force of division and consensus, rhetorics based on identity etc. in France and in all other historical and cultural contexts.

All phenomena relating to the evolution of humans (and animals) and the development of civilisations, societies, languages and cultures can be addressed. The emphasis can be placed on cognitive and linguistic abilities: contexts, perimeters and issues in the use of vehicular languages, as well as ancient, regional and endangered languages, relationships with new computer languages, new writing and reading practices etc.

This section focuses on the processes of creation in all periods: the **genesis, circulation,**

reception and interpretation of works (artistic, literary, musical, theatrical, cinematographic, televisual, video games), but also **creators** (their career paths and networks) and the texts and **works** themselves based on old or **new corpora. The circulation of models and ideas between the arts and between areas of culture** and the migration, metamorphoses and hybridisation of forms should also be considered. The practical consequences (didactic, polemical, ideological) that works may produce or trigger may also be analysed.

The study of the relationship between emotion and creation, both in artists and in the general public, could benefit from the joint efforts of SSH and other scientific fields, including interdisciplinary projects in visual and sound studies. Projects may bring together artists and researchers working on contemporary creation or focused on **conceptual developments**, **techniques** and **meaning** in creation, **collective** art forms, the role of academic **institutions** and the **market**, the **creative economy and its legal framework**. These dimensions can be envisaged from the angle of **innovations** with a contemporary or historical perspective: **arts education**, the transmission and renewal of practices and techniques, marginal expression, the role of interpreters and **gender relations.**

Lastly, in projects able to bring together researchers and professionals, the study of the processes by which heritage is designated and preserved will identify the **social and political issues** involved, the identity politics affecting these processes and the role of public, partly public and private players. It opens the way to research into the **issues of the definition**, criteria, forms and fields of application of the notion of "heritage", its influence (national and international), its relationship with the economy and tourism: cultural landscapes, monuments, archaeological sites, **museum collections, organisations and companies, cultural institutions (including libraries) and their audiences (including reading policies and links to teaching).** The objectives of heritage protection or original research will justify paying particular attention to the **digital documentation of heritage** in the form of GIS or corpora of written, oral, visual and audiovisual archives, as long as they are associated with research questions, heritage endangered by political, environmental, demographic or tourism conditions, safeguarding methods (3D simulations, storytelling, appropriation by populations) or the rehabilitation of heritage for new purposes.

Heritage and its conservation also lend themselves to **projects involving private, public or third-sector partners in association with the social sciences and humanities**. Researchers can study the transformation of rural, urban, industrial, landscape and religious heritage through the different forms of heritage management and the removal of heritage status as well as **cultural policies** and their history (classification, labelling, preservation, financing, management, but also cultural, intercultural and artistic education and policies of mediation). The role of international bodies, states and regional authorities and their mutual relationships could be analysed, as could the role of cultural and heritage administrations.

B.9 – Research to be conducted in response to the "Freedom and security of Europe, its citizens and its residents" challenge

Introduction

Research relating to the "Freedom and security of Europe, its citizens and its residents" challenge requires an integrated approach to risk management in both the physical world and cyberspace. This involves characterising threats and vulnerabilities, developing prevention and the protection of property and people, managing crises and analysing instruments, including legal mechanisms, that contribute to the exercise of individual rights and freedoms.

In a context where security is associated with perceptions and the management of risks, and with social responsibilities and their impacts, the "Freedom and security of Europe, its citizens and its residents" challenge focuses on **the issues and consequences** for the public and private organisations and institutions responsible for security, risk professionals and populations, regardless of the **risks envisaged**.

This challenge therefore mobilises the lessons learned from sociology, economics and legal disciplines as well as from technological research. It covers the security of persons and the fight against terrorism and crime, emergency assistance and human protection and the multiple procedures for searching for and managing evidence. It also relates to the protection of vital infrastructure and networks as well as the protection of sea, land and air spaces and their borders. All these aspects imply the essential need to respect personal privacy and protect personal data and human dignity.

Basic or very preliminary research is needed to help create a core of knowledge using an **integrated approach** that brings together natural and environmental sciences, digital sciences, engineering and all social sciences and humanities. This research is invited for theme 1.

For the other themes, the involvement of end users, specifiers and operators is encouraged, along with consideration of the priorities expressed by CoFIS (the French security industries committee)[6] and other vital sectors (energy, networks, transport etc.).

B.9 – Theme 1 – Subtheme 1.1: Basic research related to the challenge

Theme 1 is devoted to basic research and the constitution of a high-quality core of knowledge paving the way towards social and technological evolution in security. **It thus welcomes projects that do not primarily target direct applications covered by the other themes but have research objectives that nevertheless fall clearly under at least one of the more application-oriented themes (themes 2 to 5) of the challenge**. Research is encouraged in three major fields: social sciences and humanities, digital sciences and non-ICST sciences and technologies.

The **social sciences and humanities** are strongly encouraged: innovative proposals for the human element of security and basic research with a significant impact on public policy, on possible developments and changes in collective and individual behaviours, including the goal of improving security policies and the reliability of the associated

[6] http://www.gouvernement.fr/comite-de-la-filiere-industrielle-de-securite-cofis

technologies, and on the investigation of new fields based on an integrated approach.

Science and technology are also at the heart of prevention, surveillance, detection, identification, crisis management and resilience issues. Proposals targeting technological breakthroughs (and overcoming their potential for misuse) and new application concepts are particularly eligible.

Multidisciplinary and interdisciplinary research is encouraged.

B.9 – Theme 1 – Subtheme 1.2: Risks, crisis management regardless of origin, resilience of systems

The goal of this theme is to propose approaches, methods and tools to identify and evaluate risk situations and how they evolve, prevent crises and be in a position to manage them to limit their consequences and prevent them from recurring. Narrow analyses of crisis management are outside the scope of this theme. Priority will be given to large-scale crises in terms of their impact on society. More local crises may, however, be considered if the research extrapolates from the results beyond the situation being considered.

Knowledge and anticipation of risks and threats

This topic concerns global approaches to technical or sociotechnical systems or organisations throughout their life cycle, which, if disrupted, are likely to bring about a crisis; the goal is to prevent these crises or minimise their magnitude.

In order to build up the ability to anticipate, studies must focus on methodologies, methods of organisation and decision support tools. Studies can be based on modelling, forecasts and exploratory scenarios or the use of big data (weak signals or early-warning signs, consideration of invisible factors or neglected phenomena, elements introducing variability etc.). The expected studies involve: 1) the analysis of human factors at all scales, including social psychology and behavioural, organisational and management science; 2) the analysis of the legal and economic impact from a standpoint of the costs of failures avoided and/or gains in efficiency (direct or indirect) from introducing security solutions; 3) the integration of renewed indicators and especially of human and social factors into the process; 4) approaches to ensure the safe operation of interconnected systems.

Integrated approach to crisis management

The goal is to minimise the impact and duration of the crisis by **preparing, equipping** and coordinating the people and organisations responsible for responding to a crisis when it occurs, from the detection of warning signs to final resolution. Research could relate to information-sharing and decision support systems; the modelling of probable developments, such as “domino” effects, taking players’ capacity to react into account; the modelling and simulation of critical phenomena (natural or man-made) and the capacity to acquire and convert hybrid data from multiple sources into relevant information in real time, with appropriate human/system interaction; crisis communication with the general public, information dissemination and transparency and the organisation and collaborative processes of emergency aid, evacuation and intervention.

Putting sociotechnical approaches into context through experiments and realistic operational exercises will be useful in evaluating the relevance and validity of these

models and simulations and correcting them. The use of "serious games" may be considered for modelling crises and training relevant personnel. Major efforts should be focused on the skills needed to deal with the effect of surprise, make decisions under intense time pressure and understand the dynamics of the system and the sociotechnical organisation, even when they are outside the known field of operation.

System resilience, restoring normality and post-crisis analysis

Here the focus is on managing the end of the crisis, the subsequent period and the consequences. In the short term, there are logistical issues and the need to support and monitor individuals affected by disasters from a psychological, health, social, legal or financial standpoint. These consequences could be studied over time. For the medium to long term, research will look at the development of retrospective analysis methods and tools (feedback from crises that have been resolved or avoided) and how they can be used to prevent other crises from occurring or to mitigate their effects, as well as the legal processes for preparing standards and everything that contributes to the robustness of the legal framework.Research will examine the development of resilience, particularly in complex interconnected systems, but also the resources and organisations used to manage crises and restore normality.

B.9 – Theme 1 – Subtheme 1-3: Fighting organised crime, terrorism and violent radicalisation

This theme covers the fight against major threats to property and people, society and the environment. It covers the anticipation, prevention and management of organised crime, terrorism and violent radicalisation.

It also encourages legal or technical experiments to collect and process data to prevent or explain these phenomena, and may include technical and organisational aspects and a legal or regulatory framework.

Innovative technologies in equipment for the security forces

The research expected covers preparing and equipping the people and organisations involved in risk prevention and in restoring safe conditions, protecting emergency personnel and effectively controlling people with restricted freedom of movement (in space or over time).

Security of buildings and locations open to the public

Efforts should be made to propose solutions, preferably non-intrusive, to detect, identify and counteract all types of threat associated with terrorism or organised crime. The security of vitally important infrastructure is dealt with in theme 5.

Fighting violent radicalisation

All types of radicalisation, known or emerging, leading to acts of violence should be considered. The focus here will be on any mechanisms that can be used to prevent, monitor, analyse and counteract the violent radicalisation of individuals or groups of individuals. These include the analysis of social, cultural and geopolitical contexts favouring trajectories of radicalisation, analysis of speeches and arguments, and strategies and policies for prevention and de-radicalisation. The aim is to develop general methods for the detection of potentially risky or extreme behaviours, including the perception and analysis of weak signals.

Fighting organised crime and terrorism

The research aim concerns the fight against organised crime and terrorist activities. Research may be directed towards:

- Detecting threats reliably, quickly and economically, identifying and neutralising them, including the development of autonomous or unmanned detection systems; methods of controlling flows (people, goods, vehicles) that can also be used to automate control and verification processes without necessarily making them systematic; the detection and analysis of weak signals in the physical world and on the Internet (text, visual and sound data, reports, false documents etc.) and new surveillance and alert techniques. Interactions with citizens such as calls for witnesses or reports may be included;
- The identification and protection of leads and clues for the management and admissibility of evidence in judicial investigations, including the analysis of hidden financial flows; mechanisms to identify and pursue perpetrators and repair damage to people and equipment; and technologies for the detailed CRBNE analysis of samples;
- Reinforcement of the organisation and operation of the forces of law and order (equipment). Research into public surveillance and protection policies and their legal consequences is also necessary, together with socioeconomic comparisons of the impact of security breaches with the impact of proposed solutions.

B.9 – Theme 1 – Subtheme 1.4: Cybersecurity: freedom and security in cyberspace, securing information systems, fighting cyberterrorism

This theme considers the risks, threats and vulnerabilities stemming from digital technologies in our highly interconnected societies. Research involving encryption, biometrics, virology, multimedia data security, security of software and hardware systems, artificial intelligence and the processing of big data for security as well as for law, economics, behavioural sciences, sociology etc. is welcome. The transparency of innovative solutions is encouraged (verifiable open-source applications) to boost trust and reduce vulnerabilities by pooling expertise. Security and data protection must be taken into account from the design stage.

Protection of information devices and systems

This theme involves proposing innovative approaches to cover the need to protect information systems and all the devices that produce, process and store sensitive information. The aim is to ensure the protection of citizens, institutions, infrastructure, networks and tangible and intangible assets. The scope of research may range from the security of basic components (including cryptography) to the security policies of a system of interconnected systems, via digital data protection and human and organisational factors. It will also focus on cybersecurity for the instruments of e-government (administrative procedures, digital health insurance cards or identity cards etc.) and e-democracy (electronic voting), security technologies for the components and systems of the Internet of Things and the threat from the emergence of quantum computing.

Projects may relate to initiatives that raise awareness and offer multidisciplinary training for cybersecurity staff and tools to help with learning about security solutions.

Cybersecurity for infrastructure, physical networks, equipment and objects

The growing role of digital technology in the operation of physical systems, equipment, infrastructure and networks is creating new vulnerabilities. The risk considered here is not just data theft, but malicious changes to software or information, as re-configuring controllers could lead to critical situations. This risk is increased by growing levels of interconnection with, for example, smart meters, industrial systems, connected vehicles and applications involving connected objects more generally.

Fighting cybercrime and cyberterrorism

The focus here is on the use of digital technologies for illegal activities or activities that jeopardise the proper functioning of public institutions and businesses and threaten individuals. Research will address methods, resources and tools for combating criminal or terrorist cyberactivities. Projects may involve the detection of weak signals in streams of big data, behavioural analysis, the processing of web content, social networks, virology and the fight against malware, in strict compliance with ethics and the applicable legal rules. Research into cyberattack issues may be considered, especially in the social sciences and humanities, again in strict compliance with ethics and the applicable legal rules. It may also examine methods of combating the illegal and unethical behaviours made possible by anonymous use of the web.

Protecting fundamental rights and freedoms in cyberspace

Research should contribute to developing a framework of trust that will enable companies and organisations to innovate and offer products and services that meet the needs of consumers and society, taking changes in national and European regulations into account. This framework of trust must involve including ethical and legal issues in all research projects dealing with security (ethical evaluation, incorporating data protection from the design stage) as well as research projects about citizens' power to act (information, data management and control).

Research combining technological knowledge and knowledge from the social sciences and humanities on how to make sure that individuals retain control over their data and their exchanges (data decentralisation, encryption, anonymisation techniques, tools for data control and portability, etc.) will be particularly encouraged.

B.9 – Theme 1 – Subtheme 1.5: Protecting vitally important infrastructure and networks, monitoring sovereign areas

The vulnerability of vitally important network infrastructure and sovereign spaces has risen considerably under the combined effect of the increase in destructive capacity, the proliferation of potential targets and media coverage of attacks. It is therefore important to provide a global, organised security response involving a precise, forward-looking assessment of the risks and threats and their consequences, vulnerabilities and the preventive and protective measures to be implemented.

This theme is therefore seeking proposals for technological building blocks and research work (methodology, modelling tools, metrics) on formalising the definition and/or verification of compliance with the safety and security requirements of these targets for the purpose of designing or evaluating systems at risk of attack; diagnosing situations (affecting sites or data flows) and the potential impacts for all parties involved; evaluating the cost/performance of sociotechnical solutions, to assist in choosing an appropriate preventive/protective system; analysing operational data (regardless of its

scale) to identify weak signals in order to forestall an attack; suitable representations (HMI) of situations and graduated alert signals for effective operational surveillance and decision support.

In the interests of developing cost-effective solutions, projects proposing solutions that combine safety and security requirements will be appreciated. The fruit of this research could potentially result in the development not only of more sophisticated technological building blocks but also of best practice, reference points and even standards that could be developed in other research contexts focusing more on applications.

Protecting vitally important infrastructure and networks

This theme involves studying and reducing the vulnerability of critical infrastructure and physical networks (and related services), especially relating to energy, water supply, transport and telecommunications. Attention should also be paid to preventing and managing successive disasters (domino effects) involving these types of infrastructure. This theme also concerns research on the combination of natural and technological risks (natech).

The aim is to anticipate threats and vulnerabilities and to propose solutions to prevent risk situations or to protect against their consequences. The management of crises resulting from the occurrence of such situations falls within theme 2 of the challenge. Research projects may include characterising and assessing the effects of risk or threat scenarios and protection against all types of risk and threat based on an approach that involves integrating security at the design stage. Potential targets must be understood in the broad sense and include tangible, intangible and human assets. Finally, adapting the legal and normative foundations associated with current and future security challenges should also enhance the research performed under this theme.

Regardless of the sites involved, it is important to monitor, locate and protect people and property in real-world and digital environments. It is appropriate to consider the infrastructure environment to optimise the complexity of the solution and seek a balance between technical and human approaches and doctrines. In this respect, preference in research must be given to the integrated analysis of natural, technological and human risks to propose preventive responses; similarly, research relating to scenario evaluation approaches or tools, be they organisational or technological, may be proposed.

Maritime, land and air surveillance

This theme involves studying threats and managing the security of flows of humans, tangible goods (logistics chain) and intangible goods on sea, on land and in the air and through the interconnections between these different spaces. In particular, it addresses sociotechnical systems for continuous remote surveillance, which may involve automatic methods (image, scene or movement analysis), robots and drones. It also covers tools to improve the monitoring and traceability of people's movements within different areas, including inside buildings (private or public sites), and the detection of suspicious movements by people, vehicles, ships, aircraft and drones within areas, in compliance with the legal rules in force (including respect for privacy and keeping the public informed). Research may cover technological issues (all types of sensors, including space-based sensors, and the associated algorithms, event correlation, intervention methods etc.) and/or questions relating to the social sciences and humanities (law, political and management sciences etc.).

These studies may also define the technologies required to address smart border and invisible security concepts.

B.10 – Research outside the challenge framework

Three further themes supplement the previous 36. Their purpose is to support basic and applied research projects in scientific fields that are not covered by the priorities announced for the societal challenges.

The scientific scope of these themes encompasses a clearly-identified series of disciplines and sub-disciplines of the exact sciences within three major disciplinary fields of the Work Programme: environmental sciences and universe sciences, physical and energy sciences, and mathematics and digital sciences. It is not open to the life sciences, social sciences and humanities, which are already identified under the previous themes.

The purpose of these themes is to compile projects that are based on existing concepts or explore new disruptive or high-risk pathways. They are open to applications, interdisciplinarity and topics relating to rare disciplines that could lose knowledge due to low numbers of researchers or waning interest.

The non-challenge scientific area is broken down into three themes:

- Mathematics
- Condensed and diluted matter physics
- Subatomic physics, universe sciences, structure and history of the Earth

Research projects outside these themes must find a home among the nine societal challenges. It is up to project sponsors to choose the most relevant direction for their project. Four scientific evaluation panels are responsible for evaluating projects, and their scope is precisely defined in the text of the generic call for proposals.

B.10 – Theme 1: Mathematics (non-challenge theme)

This theme essentially encompasses the field of pure mathematics (the ERC PE01 sector): logic, algebra, number theory, geometry, topology, Lie algebras and groups, analysis, operator algebras and functional analysis, theoretical aspects of partial differential equations etc.

Applied mathematics projects with a theoretical nature that are not covered by the societal challenges are also invited for this theme.

B.10 – Theme 2: Condensed and diluted matter physics (non-challenge theme)

This theme covers a broad field of physics, consisting essentially of the ERC PE02 sectors (except the subdisciplines PE02_01 to 04): “Fundamental constituents of matter: plasma, atomic, molecular, gas and optical physics” and PE03 (except the sub-disciplines PE03_05 and 07): “Condensed matter physics: structure, electronic properties, fluids, nanosciences, biophysics”.

B.10 – Theme 3: “Subatomic physics, universe sciences, structure and history of the Earth” (non-challenge theme)

This theme addresses all basic research projects in subatomic and theoretical physics, astrophysics, cosmology, astronomy, planetary science, exobiology and the structure and history of the Earth (including remote palaeoenvironments with no equivalents in the current era). It includes three clearly-identified subthemes:

- **Subtheme 3.1 – Fundamental constituents of matter (ERC subdisciplines PE02_01 to 04)**
- **Subtheme 3.2** – Universe sciences (all the subdisciplines of ERC sector PE09)
- Subtheme 3.3 – Structure and history of the Earth (subdisciplines of ERC sector PE10)

B.11 – Research in support of major cross-disciplinary challenges

B.11 – Theme 1: Mathematics, computer science, automation and signal processing to meet the challenges of biology and health

Theme common to the "Life, health and well-being" and "Information and communication society" challenges

This theme addresses the development of concepts and new methods using mathematical, computing and biostatistical tools for:

- The analysis of large amounts of biological data generated by high-throughput omics. This theme includes the collection and management of big data, interoperability between heterogeneous data and the development of algorithms (learning methods, data mining etc.) to process and interpret the data. It also covers the use of big data for decision support, exchanges of data, access, security, regulation and data management ethics in pre-clinical, clinical, population and epidemiological research.
- cellular and tissue microscopy to develop the acquisition of complex multimodal high-content data at multiple scales, super-resolution microscopy, fast dynamic microscopy, algorithms for data analysis and quantification, including the automatic segmentation and recognition of biological objects in cells and tissues, the archiving and restoration of raw data and associated analyses, the mathematical modelling of data from quantitative cellular and tissue microscopy and virtual and augmented data visualisation.
- Signal processing and biological and medical image processing: the development of methodological tools for the segmentation, extraction and characterisation of the information contained and the fusion of multimodal, multi-scale and spatio-temporal (morphofunctional) information, The hierarchical modelling of the multi-scale phenomena observed (from the molecule to the organ and the organism) is also covered by this theme.
- The predictive analysis of biological processes and methods for comparing them with experimental data. This includes the development of morphological and functional models, models of complex biological systems providing a dynamic, quantitative understanding of complex phenomena, biomechanical models, multi-parametric models associated with clinical, phenotypic and environmental data from large databases and models for personalised digital medicine.
- The development of the simulation of complex biological systems, digital simulation, high-performance computing and the associated optimisation and immersive simulation (virtual and augmented) to integrate and represent multimodal, multi-scale data.

B.11 – Theme 2: Public health

Theme common to the "Life, health and well-being" and "Innovative, inclusive and adaptive societies" challenges

This theme is common to the "Life, health and well-being" and "Innovative, inclusive and adaptive societies" challenges, and projects submitted under it will be evaluated jointly by a single interdisciplinary panel.

The theme aims to encourage integrated multidisciplinary research in public health. This research should shed light on the state of health of populations, the health conditions and behaviours of individuals and their relationship with the healthcare professions, institutions and players in the public and private sectors.

The goal is to analyse and understand the role of social, economic, behavioural and environmental factors and their interactions in well-being, health, constitution and the reduction of health inequalities. It involves proposing a research framework to address in integrated and interdisciplinary fashion the impact of multiple determinants on illnesses and health, assess the risks, propose methods of surveillance and anticipation, prevention, responsibility for and treatment of pathologies (including in primary care), compensation for disabilities and adaptation of health policies and systems to this context. Special attention will be paid to methodologies for analysing the social, behavioural and environmental determinants of health throughout life and in different areas of activity (residential, professional etc.). In particular, an appropriate response from the public authorities requires prior analyses of the social, behavioural, psychosocial, economic and biological dimensions and the effects of certain social determinants on health and on the magnitude and nature of phenomena. The initiative also relates to the study of possible interventions focusing on the causes and expressions of social exposure, inequalities or health-related vulnerability and of biopolitics and questions about measurements and standards (definition, implementation and evaluation).

B.11 – Theme 3: Bioeconomy: specific technologies (chemistry, biotechnology, processes) and systemic approaches

Theme common to the "Clean, safe and efficient energy", "Stimulate industrial renewal" and "Food security and the demographic challenge" challenges

As set out in the "Bioeconomy strategy for France", the "bioeconomy encompasses all activities relating to the production, use and transformation of bioresources. These are intended to provide a sustainable response to various needs (food, energy, materials, chemical products etc.) and to provide ecosystem services." This theme is open to **cross-disciplinary and/or systemic approaches to the challenges of the bio-economy**, as well as the **methods and technologies** specifically or primarily associated with this field, including **biotechnologies and transformation processes** such as biorefineries. The theme covers **all bioresources** (harvested, cultivated, livestock, forestry, waste etc.) in **continental and marine** systems.

Production and mobilisation of bioresources

The research fields here mainly cover:

- The exploration and characterisation of **continental and marine biodiversity**, including microbial consortia, for the development of bioresources of interest. All clades are covered;
- Varietal innovation in traits defined as favouring suitability for use, for

transformation processes and for the sustainability of production systems;

- The design of sustainable cultivation systems constrained by the use of the bioresources produced;
- The exploitation of traditional or new bioresources in order to reuse marginal, degraded land and change the use of agricultural or industrial land;
- Modelling at the scale of potential bioresource production regions, across all uses, subject to constraints (agroecology, drought etc.);
- The production of bioresources for food (microbial proteins, secondary metabolites), energy and chemical applications where there is a need to better understand and improve the energy outputs of certain microorganisms (production of lipids, sugars, hydrogen etc.).

Bioresource transformation (including biorefineries)

In the context of the search for alternative raw materials, scaling up renewable carbon and the circular economy, including the cascading use of bioresources, is part of the answer. Pathways for converting biomass for specific or multiple reuse (e.g. in biorefineries) as energy vectors (hydrogen, hydrocarbons, etc.), chemical products and materials are major considerations. In particular, research should target:

- The development of biotechnological processes using microorganisms and/or enzymes to convert the biomass into energetic compounds and/or molecules of interest. These processes may be coupled with chemical pathways. Research must incorporate the increasing alteration capabilities of microorganisms (genome editing, high-throughput screening, synthetic biology etc.) The ability to use a growing number of enzymes, even including non-natural enzymes, is also a significant disruptive factor.
- The design, optimisation and control of bioresource transformation processes (chemical, physico-chemical, thermal, pre-processing, catalyst poisoning, separation, purification etc.), including combinations of technologies, changes in scale (including farm-based biorefineries), the many uses of bioresources and adaptation to biomass heterogeneity (variability, volumes, specifications, prices etc.).
- The design of cascading uses from primary uses (food first) to secondary and tertiary uses, resulting in the closure of the N and P cycles.
- Modelling bioresources and their derivatives (representation of biomass) and properties (e.g. thermodynamic), including supramolecular organisations (wood, materials).

Externalities and levers for the development of the bioeconomy

The aim here is to develop research focusing on:

- Improving tools for evaluation, decision support and monitoring the environmental, economic and social performance of the bioeconomy, including cascading use (LCA, risk and uncertainty assessment, industrial ecology, taking account of direct and indirect changes in land use etc.);
- Methods for evaluating the social, economic and environmental performance of

bioeconomic models, including the transition processes, which are valid regardless of the evaluation scale;

- Measuring the impact of the energy transition on primary production;
- Methods for compiling and comparing scenarios for forecasting and decision support (public and private); identifying and coordinating the relevant geographical, economic and administrative scales;
- The spatialisation and organisation of bioeconomy players: the metabolism of megacities associated with cascading biomass use and environmental biorefineries, synergies in industrial ecology schemes, coordination between players, conditions for bioeconomy deployment in the regions and support for changes of direction due to external (climate etc.) or internal (food transitions, new uses) drivers of the bioeconomy, sustainability of ecosystem services, resilience of territorial bioeconomy schemes to internal (disease etc.) or external (climate instability) disturbances.

B.11 – Theme 4: The digital revolution: relationship to knowledge and culture

Theme common to the "Information and communication society" and "Innovative, inclusive and adaptive societies" challenges

Projects submitted under this theme will be evaluated jointly by a single interdisciplinary panel. It calls for proposals where the disciplines of the social sciences and humanities work hand-in-hand with the disciplines of the digital sciences to break down the scientific barriers in either field.

Education and training

The development of digital technology for education and training applies to all levels of schooling and types of training, and makes it essential to take ethical and legal issues relating to respect for privacy into account. **Learning with digital technology** must provide all the benefits of advances in digital techniques and cognitive science. How can we define smart learning pathways tailored to the needs of individual learners? How can we track the individual progress of each learner? How can we assess proposed mediated learning solutions? Such questions call for research on modelling learning, the role of communities and networks and, more generally, exploration of how digital technology can be used to spread and maximise the phenomena that contribute to lifelong learning. **Learning digital technology** is becoming a key skill for education, in that the ability to participate in a society that uses digital communication technology at work, at home and in the civic space is a factor in social inclusion. Emphasis will be placed on digital literacy (including learning computer coding) from the earliest age and on developing a digital culture among teachers. The difficulties encountered in the transmission, understanding and use of IT concepts will be identified. **Learning in the digital era** means all the promise of large-scale, nomadic, connected equipment, which changes values and behaviours. Have the self-production of content and the ubiquity or growth of social networks democratised knowledge? Have they renewed its forms of expression? Massive open online courses (MOOC) and small private online courses (SPOC) deserve careful consideration. Research is required on the experiments launched, their ability to reach target audiences and possibilities for improvement, including forum analysis, automatic exercise correction and personalisation based on interactions. These educational innovations can also bring new mixed, virtual or augmented reality systems,

robots or conversational agents into play.

Knowledge creation and sharing

Digital technology affects the production, exploitation and sharing of scientific knowledge. Research may focus on how disciplines are revising their **scientific practices**. Examples include discourse analysis extended to controversies and arguments using techniques for mining textual content, or the financial economy with real-time data processing. Another topic for investigation is the competition or complementarity between digital and paper writing, between experimentation and simulation, between direct observation and research using representations assembled from data. Epistemology, cognitive science, ethics, the humanities and the social sciences can thus be applied to digital sciences and technologies. The **construction of knowledge** itself may be the subject of research on publishing and sharing processes in the context of free access to scientific publications and research data: methods of editorial control, relations between researchers or between researchers and the public (e.g. citizen science). Better self-awareness (and awareness of others) can emerge if organisations share the personal data they hold with the individuals in question. Faced with the anxiety generated by the collection and use of volumes of personal data (administrative, consumption, energy, web browsing, health etc.), the opportunities offered by the **sharing of personal data** between individuals and organisations should be explored. Individuals can then exploit the data for their own purposes, using third-party applications and services: to evaluate past decisions, take better ones and know themselves better. The use of data (big data, small data, self data) thus has social implications that raise the question of **user innovation.**

Culture and heritage

Introducing digital technology into the field of heritage (archives, archaeology, museums, inventories etc.) opens up perspectives for identification, documentation, conservation-restoration and mediation, leading to a renewal of the methodologies used to know about heritage and to make it known. **Knowledge about heritage**. New methods of acquiring and monitoring forms and materials over time and new approaches to integrating data and information are needed in order to introduce analysis, interpretation and classification materials that are more appropriate for the multidisciplinary approaches now taken to heritage objects. Digital technology also increases the possibilities for knowledge representation and transmission. How can the reproducibility of a result be preserved (e.g. safeguarding the procedures that led to the image rather than the image itself)? How can data interpretation pathways be formalised and documented by comparing technical processes with human cognitive processes? **Access to heritage**. The technologies integrated into museum premises, their web portals and their mobile apps are revolutionising the public's relationship with collections. Digital technology leads to the creation of new "objects" that are born digital, which constitute the cultural reality of new generations. Museums and sites must rethink collection management. In what form should they be made available to the public? How should they be organised and documented? Can the state apply its labelling, inventory and classification standards to tangible or intangible heritage proposed by users? How will the relationship between experts and enthusiasts evolve in this context?

*Project coordinators are invited to contact the **Huma-Num TGIR** (very large research infrastructure for digital humanities research), which organises networks of researchers looking for best practice (geographical information systems, 3D reconstructions of monuments, textural*

*analysis etc.) and is itself affiliated with the European **DARIAH ERIC**. This primarily concerns **museums** and **audiovisual archives**, such as those made available to researchers by France's **National Audiovisual Institute** (INA), whose operation requires close collaboration between SSH researchers and digital science and technology researchers and offers an opportunity to renew processing, annotation and indexing methods. The results of this research (annotations, enrichment, metadata) should preferably be **freely available** and usable for further research. Researchers interested in this huge corpus are invited to contact INA.*

Project coordinators are also invited to consider the position and role of heritage professionals in research, from the development and implementation of programmes and shared methodologies to the appropriation and dissemination of the results.

B.11 – Theme 5: Dynamics of ecosystems and their components to improve their sustainable management

Theme common to the "Efficient resource management and adaptation to climate change" and "Food security and the demographic challenge" challenges

The aim is a better understanding of how global changes relating to land use, exploitation of oceanic and land resources, biodiversity or climate will interact to affect the future of ecosystems of agronomic, forestry, fishing and aquaculture interest, whether or not they are associated with ecosystems with little or no human impact. On this basis, research will develop management and adaptation strategies in different economic, social and cultural situations and answer important questions: what will be the impact of environment and resource management methods on the environment and ecological services? How can they be changed towards sustainable management methods? What level of complementarity should be sought between natural ecosystems and production ecosystems to encourage the availability of ecosystem services (supply of resources, environmental regulation, shared assets etc.)?

Operation, adaptation and sustainable management of production ecosystems

The operation, evolution and capacity for resilience and adaptation of exploited ecosystems, both continental and marine, are still poorly understood. This is especially true of the ecological and evolutionary dynamics of species, interactions between species and between trophic levels, functional biodiversity and the contribution to the major cycles (C, N, P and water). A better understanding is needed of the interactions, continuities and interfaces between production ecosystems and systems with little or no human impact.

This research will provide an insight into the evolution of production ecosystems, their adaptation, their resilience and their ability to provide multiple ecosystem services. It will facilitate the ecological and agroecological transition by helping to design or redesign production systems based on a better knowledge of biotic interactions and functional ecology in order improve their sustainability. The objectives are improved resilience and better management and use of renewable resources, an improvement in environmental quality (water, soil, air) and a mobilisation of biodiversity, including genetic resources, maintaining its evolutionary dynamics. Research will also promote integrated management of production systems in landscapes, territories and coastal and deep-sea areas, including ecological infrastructure and semi-natural and natural environments, such as protected spaces.

Topics concerned include resource management and the maintenance of continental and marine ecosystem functions and services as well as a transition towards integrated and sustainable production systems (agroecology plan, 4 per 1000 initiative, Ecophyto plan, sustainable forest management, ecosystem approach to fishing, sustainable aquaculture etc.) in agriculture, livestock, forestry, fishing and aquaculture.

Pathways for change and political support strategies for the ecological transition in production ecosystems

The transition towards sustainable production ecosystems requires relevant pathways to be identified to encourage these changes through actions, strategies and policies. It entails analysing all the obstacles and major levers. There is a need to understand the behavioural determinants of all players faced with biotechnical and socioeconomic changes and the potential role of designing integrated, sustainable practices and production systems in collaboration with these players. Learning pathways for these players, considered as innovators in their own right, should be encouraged This entails designing new innovation pathways and integrated models combining ethical, socio-economic, biotechnical and ecological dimensions with the development of scenarios[7] to predict the evolution and adaptation of ecosystems in response to global changes.

This research should inform society and decision-makers in the direction given to production ecosystem management and the development of public policies to support an ecological transition that meets the environmental, economic and social requirements. The analysis of possible public policies should include an evaluation of the impacts of environmental transitions, taking into account biodiversity protection, climate change mitigation, integrated management of health risks and the study of interactions with bioeconomy strategies.

This work should stimulate the innovation process for the management of ecosystems, territories and production chains.

B.11 – Theme 6: Contaminants, ecosystems and health

Theme common to the "Efficient resource management and adaptation to climate change" and "Food security and the demographic challenge" challenges

This theme relates to the fields at the interface between these challenges or to particularly cross-disciplinary approaches.

It is based on an integrated rather than a fragmented vision of the environmental and health field, and is therefore based on the concept of the exposome. The study of the effects of environmental factors on living species and on human health, and the place of environment and ecosystems among the various health determinants, concerns the impacts of contaminants (physical, chemical and biological) by taking into account the different environments and exposures.

This involves understanding the phenomena and mechanisms better, assessing the risks and proposing surveillance and control methods and appropriate policies. Cooperation is therefore expected between different disciplines: biological sciences, medical sciences, ecotoxicology and ecology, physics, chemistry, mathematics and modelling, social

[7] Research by both IPBES and IPCC on biodiversity scenarios could provide useful inspiration for developing projects; see also the BiodivERsA-Belmont Forum "Biodiversity scenarios and ecosystem services" call for proposals.

sciences and humanities.

The approaches encouraged are:

- Understanding toxicity mechanisms by studying toxicity pathways or networks, systemic biology, epigenetics and vulnerable phases in the life cycle of individuals, transgenerational effects, effects of mixtures, especially at low doses, and key life history traits for population dynamics in the environment. Particular emphasis will be placed on emerging contaminants and endocrine disruptors.
- Studying the interaction between different environmental factors and different contaminants and their possible cumulative effects at all scales of biological organisation through the notion of the exposome.
- Understanding ecodynamics and modelling transfers of contaminants in different habitats and trophic networks, their integration into animal and human food chains and their impacts on ecosystems and their components.
- Characterising emerging risks for ecosystems and populations and establishing adequate surveillance systems.
- Improving the predictive capabilities of assessments of threat and risk for ecosystems and populations through systemic approaches.
- Analysing the relationships between environmental changes and chronic non-communicable and/or allergic diseases, including the context of occupational health.
- Understanding the environmental, economic and social factors that determine or modulate the exposures and vulnerabilities of human populations.
- Analysing the social conditions in which these environmental risks are assessed, discussions take place, social players are mobilised and decisions are taken.

B.11 – Theme 7: Health and environment, including the One Health concept, emerging or re-emerging infectious pathogens and diseases and resistance to antimicrobial agents

Theme common to the "Efficient resource management and adaptation to climate change", "Life, health and well-being" and "Food security and the demographic challenge" challenges

The One Health and EcoHealth approaches constitute a functional research framework for the integrated and interdisciplinary exploration of i) interactions between environment, animal health and human health and ii) the role of the environment in the appearance and persistence of pathogens, the emergence and re-emergence of infectious diseases and the development of resistances to anti-infectious agents.

The first section (which relates solely to the "Efficient resource management and adaptation to climate change" and "Food security and the demographic challenge" challenges), involves gaining a better understanding of the phenomena and mechanisms, assessing and anticipating risks and establishing how they are perceived by the social players involved in order to introduce suitable policies (surveillance, combat and treatment). Cooperation is expected between the different disciplines of the biological and medical sciences, environmental and ecological sciences, physics and chemistry, mathematics and modelling, evolutionary ecology

and the social sciences and humanities.

The second section (common to all three themes) focuses more specifically on how pathogens spread and the emergence mechanisms for infectious diseases (human, plant or animal, including zoonoses) in conjunction with environmental and anthropogenic factors: reservoirs, vectors, ecological niche, persistence and development conditions, virulence, spatio-temporal dynamics, transmission, risk of inter-species transfer, multiple resistance, control and surveillance methods, prevention, identification of populations and areas at risk, preparation for the risk of epidemics and pandemics and the social conditions of systems for dealing with epidemics. All pathogens are concerned, regardless of their origin and products, together with resistance to antimicrobial, antiparasitic and antifungal treatments, insecticides and biocides. Research is encouraged on the modelling of emergence, spread, exposure or elimination parameters, retrospective analyses and the creation of databases to help define indicators for a predictive approach to epidemic evolution in the context of health monitoring.

B.11 – Theme 8: Interactions between humans and the environment: societies, climate change, sustainable regional development, food security

Theme common to the "Efficient resource management and adaptation to climate change", "Food security and the demographic challenge" and "Innovative, inclusive and adaptive societies" challenges

Social, cultural, economic or political changes, methods of societal organisation and governance and development conditions are all essential factors in adapting to environmental changes and taking vulnerabilities and the management of habitats, risks and food security into account. All the disciplines in the social sciences and humanities (sociology, anthropology, law, history, economics, management, archaeology, geography, philosophy etc.) and environmental sciences (ecology, hydrology, climatology, agronomy, physical geography, development etc.) are concerned. This cross-disciplinary theme has three subthemes.

- ***Societies in the face of environmental change***

Reducing the environmental footprint of human activities requires appropriate modes of development and governance, taking into account vulnerabilities and social, cultural, economic and political changes affecting the conditions of adaptation, but also natural and technological risks and resource depletion. Research may address different temporal and spatial scales and approaches that focus on single or multiple sectors in different areas. Comparative or community-based research analyses are welcome.

Policies and players, actions and instruments

How do public and private players contribute to constructing environmental problems – including emergencies and risks – and how do they recommend and disseminate their solutions? How can power relationships, coalitions, controversies and legitimisation mechanisms be reconfigured? What role does scientific knowledge play at the interfaces between decision and action?

Public action can be understood through the models and instruments used or the learning and cooperation patterns it involves. It is important to identify and evaluate innovations in this domain, such as recourse to paying for ecosystem services. Research should be extended to the position of regional players, their role in change and the

coordination of different political and administrative levels.

Interconnections between policies raise the question of their cumulative effects, their contradictions and the possibility of making the goals of the Paris Agreement consistent, especially when subject to constraints. These imperatives call for more research on innovative mechanisms and the evaluation of public policies and of actions.

Conflicts, cooperation, governance

Environmental changes, which are potential factors in conflicts and new power relations, can be amplified by the effects of certain conflicts. The interplay between development modes, environment, vulnerability and international relations deserves to be explored further.

After the adoption of the global sustainable development goals and the Paris Agreement, what role can the United Nations organisations and agencies play in the future? Is a new relationship between national sovereignty and transnational governance involving non-state players emerging to manage common global goods? What role do jurisdictions play in this system? Can the growing fragmentation of international legal regimes be overcome?

Vulnerabilities, inequalities, resilience and adaptation of societies

Climate change forces a move beyond approaches based on individual risks to develop multi-risk, inter-sectoral scenarios integrating totally new effects. The notion of resilience highlights societies' unequal capacities for resistance and adaptation. What factors encourage adaptation to sudden or gradual extreme events? What is the relationship between social representations, the reality of risks and adaptation and management strategies?

The historical analysis of dynamics helps in understanding environmental risks, including the study of periods of cultural, environmental and climatic disruption and of past disasters. What role do memory and knowledge play in understanding/assessing environmental risk in different cultural settings? How can consideration of the long term modify perceptions of actions to be taken, and how do they interact with other time scales? Research may cover vulnerable areas (intertropical, island etc.).

The various forms of cultural expression can be analysed from the point of view of their role in the collective memory, in representations of risks and disasters, visions of the future and possible worlds.

Production and consumption, innovation and growth

Adaptation is reliant on management, production and consumption patterns that use few resources, especially in terms of energy. How can innovative players, new products and sectors, short supply chains, the circular economy and new forms of economic organisations be encouraged? What are the obstacles – including in training – that slow down the dissemination of innovative technologies and services and changes in consumption patterns, and what instruments can overcome them? Technology can be examined through its objectives, forms of legitimisation or the controversies it sparks, its patterns of dissemination and its relationship with existing infrastructure as well as its effects on social organisation, the environment and health. Which new forms of development and growth, incorporating environmental requirements and the depletion of certain resources, can be envisaged? How can land management, environmental

protection and economic efficiency be reconciled?

Justice and accountability

Societies and social groups are unequal in the face of risks and of the need to adapt. The issues of equity and environmental injustice warrants further exploration in terms of access to resources and amenities, the appropriation of common property by private interests or exposure to the negative externalities of development methods. Which indicators should be used and what importance given to this dimension in implementing public policies? How can "intergenerational justice" be designed and implemented?

- ***Integrated approaches for sustainable regional development***

The aim here is to promote **integrated scientific initiatives** that emphasise the complex interactions between ecosystems and socioeconomic systems.

The characterisation and analysis of interactions between habitats, uses and practices based on integrated or systemic approaches constitute the expected starting points for (i) addressing changes in practices, behaviours and the management of resources and regions and (ii) anticipating, identifying, facilitating and amplifying transitions. This research should contribute to the adaptation and/or greater resilience of socio-ecosystems faced with change.

Projects will be based on spatial or temporal approaches on multiple scales explaining the internal interactions and external forcings affecting the targeted socio-ecosystem. Particular attention will be given to joint projects with socioeconomic players[8] involved as partners. They may include short exploratory projects helping to build innovative consortia and large integrative projects on questions that have already been raised.

Ecosystem services: evaluation, competition and arbitration

Identifying ecosystems services, and environmental services more broadly, by characterising, quantifying and evaluating functions (particularly in economic terms) is part of a booming research area that is stimulated by a variety of national and international initiatives (International Convention on Biological Diversity, IPBES, French Environment Ministry etc.). These services may be analysed, if necessary, by environmental compartments, taking into account the multiple functionalities offered and the limits of single-service approaches. Where appropriate, these issues may be addressed through retrospective studies of the processes by which these services are identified.

Sustainable management and resilience of territories of strategic environmental importance

As well as reducing or mitigating the cumulative environmental impact of human activities, the sustainable development of a region involves societies adapting to increase their resilience. This implies assessing a region's potential in order to achieve better management in the medium and long term at an "intermediate" spatial scale (typically the scale of a landscape or from a small basin to a large region, from 1 to 100,000 km^2). Retrospective analyses may provide transposable avenues for adaptation and mitigation. The research expected will bring together researchers, local players in the socioeconomic world and/or public policymakers around a shared problem and a

[8] Associations, companies, local authorities, public-sector operators etc.

common territory. Scenarios and modelling could inform planning and support methods for regional projects. Research objectives and methodologies will be careful to take social and political factors into account, such as different perceptions of where problems lie and of socially acceptable solutions.

Under the research aspect of NCCAP (the French national climate change adaptation plan), research is invited to redefine climate change adaptation policies and conditions for their implementation, notably in especially vulnerable and/or insufficiently-studied territories such as coastal areas, intertropical zones, the Mediterranean area and cities.

Integrated risk evaluation chain, incorporating hazards, vulnerabilities and impacts on territories

Global changes affect the scale and scope of environmental risks to populations. The objective is to improve risk forecasting and increase socio-ecosystem resilience. Climate forcing, mechanisms influencing hazards, the identification of exposed areas and the unequal vulnerability of socioeconomic players are all factors in assessing environmental risks.

Projects will evaluate secondary effects, such as multi-hazard components, domino effects, tipping points, interactions between natural, industrial and technological risks and feedback. Dealing with this risk chain in areas at risk, identified geographically, should extend to questions of economic evaluation, perceptions and representations of risk, the suitability of mechanisms for public action and the consequences of failing to take the risk into account (e.g. continued building on floodplains or in landslide risk areas).

- ***SSH knowledge base for food security and ecosystem sustainability***

A number of generic research themes cutting across these issues need to be explored, including:

- **The behaviour of actors** and of socio-ecosystems in response to innovations, system changes and risk, the role of beliefs and representations in behaviour: economics and behavioural sciences, social psychology, anthropology, history and sociology (individual and collective behaviour);
- **The dynamics of collective mobilisation**, both for the management of an ecosystem or a resource exploited jointly and in terms of training, innovation and collective change;
- **Public policies**: design, implementation and evaluation, including experimentation processes;
- Modelling integrating biotechnical science with social science at different spatial scales.