

EPHemeris

Earth and Planet Habitability



Scientific interest groups: OHM Pays de Bitche, GISFI, ZA Moselle

Challenge: Ecological Transition (One Earth)

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Description of the ambition and long-term vision

Humanity and the planet Earth have now entered the Anthropocene. This change of era is characterized by human activities becoming the major driver for all ecosystems. These disturbances are causing rapid changes, at both local and global scales, in the regulatory processes of our planet's surface^{1,2}. They are threatening the sustainability of our societies by calling into question the climatic zones, the quality of natural environments and their ability to provide ecosystem services^{3,4}, our health and lifestyles as well as the associated geopolitical stability. It is now obvious that (i) the capacity of human societies and other living species to continue to inhabit their environments in the future is compromised and (ii) the way some societies interact with ecosystems have to be reconsidered⁵. The question of habitability of our planet is thus central for understanding the maintenance and adaptation of animal/vegetal species and societies at all temporal and spatial scales.

Addressing the question habitability requires to understand the conditions that enabled life to appear on Earth (and perhaps on other planets) following its formation 4.5 billion years ago^{6,7}, which represent a scientific and philosophical challenge of the highest order. Beyond the emergence of life on Earth, the conditions for its maintenance are also a fundamental question. Between massive volcanic eruptions, asteroid collisions and extreme climatic changes, often accompanied by mass extinctions, the history of the Earth's environment has been punctuated by numerous global crises. Whether in the distant past (several tens to hundreds of millions of years), more recently during the Quaternary era, or currently in the Anthropocene, the complex processes of disruption and resilience at play during these crises remain poorly understood^{8,9}. Questions regarding Earth's future habitability evolution and its environments, and our ability to reliably model them, must consider lessons from the past, and rely on specific and precise documentation of environments over both short and long timescales. On the other hand, understanding the future evolution of Earth's habitability under the pressure of local and global changes requires a systemic and interdisciplinary approach. This approach is essential for quantifying the different forcing, the multitude and combined risks¹⁰, and their impacts on biological systems, our societies and the human-environment interactions at work within socio-ecosystems especially regarding path dependence along STEEP (*i.e.*, socio-technological-economical-ecological-political) dimensions.

To address these present and forthcoming changes, a paradigm shift is necessary in how we approach the processes governing interactions between ecosystems and human activities (*i.e.*, reaffirming the pre-eminence of bio-physical-chemical processes over economic principles). This requires bypassing scientific barriers that today preclude positioning the question of planetary habitability at the center of our societies^{11,12} as well as understanding and overcoming the profound divergence in the perception of risks, opportunities and challenges associated with competing visions of future development directions toward a sustainable future. This could only be achieved by developing an interdisciplinary approach to teaching, research and public communication (Fig. 1). For this purpose, specific points must be taken into account:

- 1- The processes that have controlled the past functioning of our planet as well as those that may relate to extreme, extraterrestrial or very primordial conditions.
- 2- The conditions and parameters controlling the adaptation of living species and societies across all scales of time and space, from the formation of our planet to the Anthropocene.

3- How anthropic activities and their – often negative – externalities (soil and water degradation, destruction of biodiversity, massive use of chemical substances, deforestation...) disrupt ecosystems' habitability and, in return, affect the sustainability of human societies.

These points represent the heart of the EPHeMeris project, which has initially been designed by scientific communities with different but complementary skills (i.e., geology, environmental sciences, social and human sciences). Our ambition is to set up a comprehensive project around the question of habitability in order to (i) gather and federate the diverse scientific communities of the University of Lorraine, (ii) train the next students' generations and (iii) provide integrated knowledge to teachers, general public, and economic and political decision makers. To do so, we propose an approach integrating scientific research, technological developments, deinnovation processes, academic training, continuing education, public communication and citizen participation. It is worth noting that this proposal stems from three days of collective discussions involving cosmochemists, geologists, urban planners, ecotoxicologists, economists, soil scientists and researchers in information and communication sciences in addition to interested parties and stakeholders from the civil society (Fig. 1).

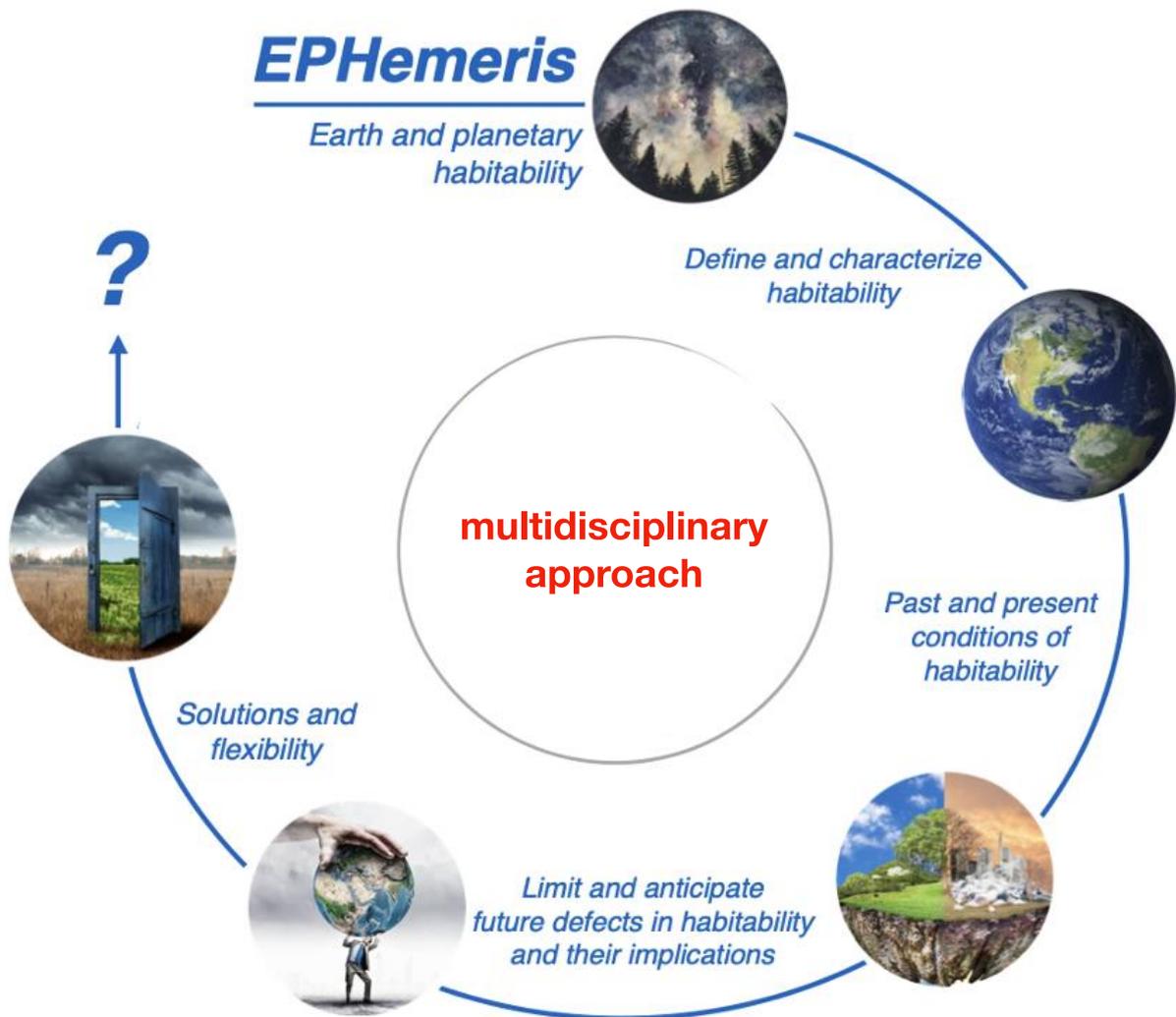


Fig. 1: Schematic representations of the scientific approaches represented within EPHeMeris and the fundamental questions this project will address.

The EPHEmeris project aims at stimulating research actions regarding habitability as a concept to foster the emergence, within the University of Lorraine, of an interdisciplinary community able to tackle this fundamental issue. The project's objectives are ambitious, multifaceted and involve a multi-scalar and interdisciplinary approach:

1- Defining and characterizing the concept of habitability. Habitability harbours different definitions and can be approached in various ways depending on the discipline. In environmental sciences, it involves predicting whether the physical characteristics of the environment (*i.e.*, climate, hydrology) align with the requirements (*i.e.*, physiological, ecological, psychological, social) of living beings to maintain the functionality of ecosystems. From the human and social sciences perspective, it can be seen as one of the three main modes related to materiality and its representations: subsistence (extraction of resources for the living community), habitat (place ensuring security for the collectively formed) and knowledge (describing and thinking about the environment). A key objective is thus to build the most comprehensive definition of habitability by integrating viewpoints from each discipline regarding the concept and its application to different living organisms.

2- Identify, understand and measure the conditions of past and present habitability. The long-term objective is to understand how the Earth and planetary systems formed and evolved toward conditions allowing the appearance and development of life. Particular attention will be given to the study of water origin and distribution in our solar system and its role in the evolution of our planet and its habitability. It will also be essential to investigate the major extinctions and crises that have occurred through time along with their impact on biological evolution and the history of terrestrial environments. This is a prerequisite to anticipating the upcoming major changes predicted for our planet and all ecosystems.

3- Limit and anticipate future habitability defaults and their implications. We aim to understand how environmental disturbances linked to human activities (climate change, water and soil pollution, habitat degradation, alteration of biogeochemical cycles, overexploitation, biological invasions) affect territories and ecosystems of our planet as well as induce climatic, hydrological and geomorphological hazards. The impact of these phenomena on the future habitability of the Grand Est territories and ecosystems will be studied. This will help predict and mitigate crises in biodiversity and similarly crises affecting our societies' proper functioning. Thus, the project aims to guide all aspects of regional planning regarding these issues. The project will also focus on quantifying the development of socio-environmental stresses related to climate change and the psychological and physiological responses of individuals to this stress. Since this stress can be a factor of inertia, mitigation solutions have to be found to make it a driver of societal changes especially to overcome lock-in effects and path dependencies. The project will contribute to the definition and calculation of critical limits of habitability and adaptation for humans and different living species on planetary and regional scales. These limits also need to be characterized for the extraterrestrial domain, given that the international space conquest race has been relaunched.

4- Propose solutions that take into account the complexity of bio-physical-chemical processes and how they are perceived by human societies. The objectives are multiple. On the one hand, it will be necessary to reflect on (i) what nature (or what idealized state of nature) the human species can/wants to return to or maintain^{13,14}, (ii) what means society is willing to implement, and (iii) what concessions society is prepared to make to reach this objective. A challenge is to go beyond technosolutionism and to initiate a shift in our way of life. The collective appropriation of these stakes must pass notably through (i) a better capacity to communicate and to reason over a long time,

(ii) understanding the role of the perception and socio-cultural representations of the past crises, into our anticipation and our acceptance of the changes to come and (ii) to determine how imaginary scenarios and available/future narratives can influence the actions and necessary societal evolution. On the other hand, it will be necessary to determine which measures are the most effective (efficiency/acceptability compromise) to restore ecosystems and their functionalities. This will require evaluating their resilience/resistance to different stresses, whether of anthropogenic origin or not, thus limiting the impact of the changes underway on human societies. Finally, the question of extraterrestrial habitability as a possible future for humanity is raised. Beyond the scope of classic scientific or fictional representations, can our societies really conceive and construct realistic habitability projects outside our terrestrial environment?

Our approach can thus be summarized with the following mottoes:

Learn from the past, understand the present, anticipate the future

Think global, act local - Think local, act global

The long-term ambition of this project is to stimulate research into the concept of habitability and turning EPHemeris into a major scientific and educational think-tank. The concept of habitability is currently emerging in public debate and becoming a political issue. An interdisciplinary research approach is therefore essential, and the project will involve interaction with non-governmental actors, economic world, political decision makers, teachers and trainers and researchers – all stakeholders that are in fact the main recipients of the results produced by EPHemeris. Our goal is thus to foster communication (i) between sciences from different epistemological traditions (social sciences, humanities, physical sciences, environmental science, material and process sciences) and (ii) between different groups of actors and stakeholders in our societies. The EPHemeris project will act as a catalyst for these interactions in order to allow for spillover effects. It will also address these issues with openness, transparency and within the framework of open science in order to (i) communicate the daily actions of researchers to a large audience, (ii) show the complexity of the interactions at stake and (iii) lead to concrete solutions. We emphasize that EPHemeris will be a project open to the entire UL community throughout the lifetime of the project.

Research and Project Objectives

Having described the long-term vision of the EPHemeris project, we will now go on to detail the concrete building blocks envisioned that will guide the project over its 4-year life. Following workshops organized by the EPHemeris community, research into habitability will be conducted on a matrix basis, corresponding to transversal research objectives (**Fig. 2**). Regardless of the scale of time and space, the EPHemeris project will seek to better establish:

- 1- The conditions of habitability, taking into account its complexity and diversity.
- 2- The fragility and vulnerability of habitable conditions.
- 3- Societies' and ecosystems' adaptability to habitability changes.

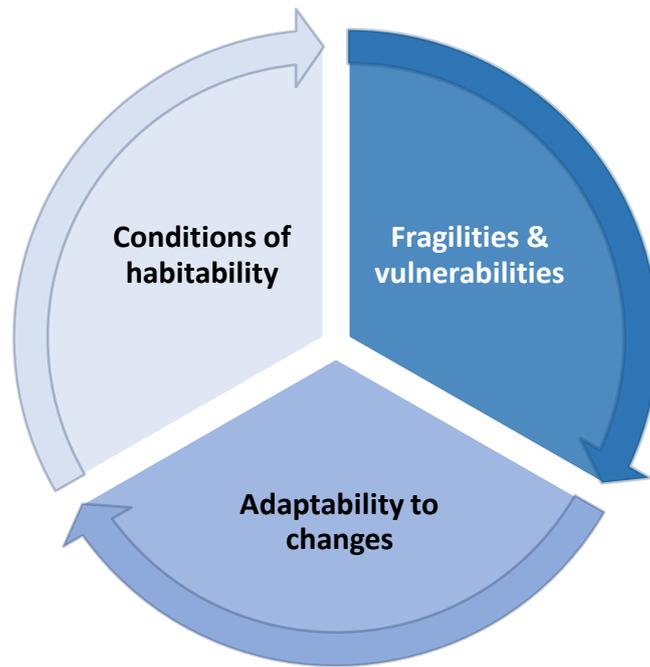


Fig. 2: Ephemeric's research matrix

Three main work packages will be set up to structure EPHEmeric project from the outset (**Fig. 3**). These will evolve as the project progresses, thanks to the already fruitful exchanges between the different approaches brought together within EPHEmeric. Moreover, aware of this project's profound challenges for the future of our societies and our ecosystems, as well as driven by a desire to produce cutting-edge scientific results, these research objectives will include a strong reflexive perspective. The following sections will outline the project's research objectives, its scientific ambitions (results, publications, new topics) and also expected outcomes for UL.

WP1 – Observatory of habitability

- Provide detailed pictures of local, national and international initiatives on habitability concepts
- Study the work carried out as part of the EPHeMeris project

WP2- Setting up and evolving living conditions

- How the Earth became a habitable planet ?
- How the Earth's geological and climatic evolution has affected habitable conditions ?
- How climate change and human impact affect ecosystems and human societies

WP3 – Communicating habitability

- Communicate the concept of past, present and future habitability
- Study the different ways of transmitting works on habitability among the various stakeholders, from scientists to civil society

Fig. 3: representation of the three work packages that will framework the EPHeMeris project

WP1 — Observatory of habitability

By creating the first “Observatory of habitability”, EPHeMeris aim is to create a structure that will identify the project as a major key player on the question of habitability within the scientific community and within interested networks on this issue. Like other observatories, its goals will be to provide both a space and a research tool allowing us the collection and compilation of data, access to research protocols or methods, and making results visible. This observatory, regrouping researcher from diverse epistemological traditions, will have two major specific objectives within the project.

First, it will have to **identify and cartography all existing scientific and non-scientific productions at international, national and local level revolving around the concept of habitability** and associated concepts. This "meta-reflexivity" approach is of fundamental importance as it will allow to:

- Identify existing organizations, inside and outside academia (*e.g.*, institutes, federations, research groups, pedagogical structures, citizen initiatives...);
- Study the different scientific, pedagogic and communication approaches that are commonly developed regarding the concept of habitability;
- Establish networks with these different structures to foster EPHeMeris' key player status.

Secondly, the observatory of habitability will be tasked to **study the works performed within the EPHEmeris project itself** and by the different task forces and financed sub-projects. This reflexive approach will allow us to: (i) closely observe science in the making and thus produce significant methodological and theoretical data on a longitudinal scale; (ii) outline the different epistemological approaches involved in different scientific fields within the community thus establishing a sensitive multidisciplinary map of habitability concepts, (iii) create a reflexive apparatus on the mediation and circulation of scientific data in the public sphere.

Altogether, this will open up a global playground for the EPHEmeris project and will enable us to structure and advance our approach, while allowing the different epistemological traditions working together under EPHEmeris' umbrella to gain in-depth knowledge of one another. Beyond the scope of the four years of the IMPACT project, we hope to perpetuate EPHEmeris's "Observatory of habitability", in order to reap long term benefits. For instance, this work-package is expected to produce first-hand scientific results on an ambitious interdisciplinary research project, identify potential cutting-edge new research dynamics and raise UL's renown in the academic community which can result in potential high-profile recruitment and new partnerships.

It should be noted that this observatory will be supported by the Lorraine Earth Sciences Observatory (OTELo), of which several laboratories involved in EPHEmeris are already members. This inclusion offers the advantage of national visibility and additional human and financial resources, as well as secure long-term results thanks to the experience developed within OTELO on data management.

WP2 — Setting up and evolving habitable conditions

This work-package will focus on major scientific projects aimed at understanding how the Earth became a habitable planet, how its geological and climatic evolution has affected habitability conditions, and how current climate change and anthropogenic impacts are affecting ecosystems and human societies. More specifically, these issues will be addressed through the prism of (i) water resources as a key element of habitability and a marker of environmental crises¹⁵ and of (ii) ecosystem resilience and resistance factors^{9,16}.

Indeed, the availability of sufficient quantities of water of satisfactory quality is one variable always essential, among dimensions that can be used to characterize habitability. Past environmental crises will enable us to describe the ecosystems, or components of ecosystems, that have been resistant or resilient in the face of these crises. These two concepts of resistance and resilience are often poorly defined, and generally summed up in the notion of resilience alone, and characterized mainly as an ability to face environmental or anthropogenic stressor, whereas it should also consider:

- The extension of these concepts to human activities
- the implications of an altered resilience/resistance for biodiversity and the organization of societies;
- the perception by human societies of the external forcings that can be exerted on the environment.

A goal of the project will thus be to propose coherent and shared knowledge and definition of the concepts of "resistance" and "resilience" in regards to the project and to the involved disciplines.

For addressing these different research axes, three backbone sub-projects will be set up to structure EPHemeris from the outset.

WP2.1 Establishment and evolution of habitable conditions on the scale of the solar system and planets.

Involved laboratories: CRPG, GEORESSOURCES, SIMPA

Context: Understanding the conditions that enabled life to appear on Earth (and perhaps on other planets) following its formation 4.5 billion years ago is a scientific and philosophical challenge of the highest order. Especially, the origin and distribution of water in our solar system and its role in the evolution of our planet and its habitability are of primordial importance, as well as the establishment of conditions that enabled the appearance of life. Current scenarios are however ambiguous and current inferences range from a local origin from hydrogen-rich building blocks⁶ to late delivery by material coming from the outer solar system¹⁷. Addressing this question would have profound implications as molecules of biological interest could also be delivered in the latter case. The same questions apply to Mars, even more so in view of the potential development of life on this planet and its possible future exploration.

Water is not only essential to the origin of life but has also a key influence on the evolution of planetary bodies. The water molecule strongly controls mantle dynamics and large-scale geochemical differentiation, the locus of partial melting in the mantle and crust, magma evolution and eruptive dynamics, the development of planetary atmospheres, and the maintenance of equable climates and planetary habitability. The fundamental role of water can be summed up as follows: no water, no granite - no granite, no continent. However, there is no consensus today on the rate of production of continental crust during the Earth's geological evolution. It hence appears fundamental to better understand the conditions for the establishment of the first terrestrial continents and the role of terrestrial geodynamic evolution and geochemical cycles on the development and evolution of habitable conditions. Already important in the past, water is set to become a critical resource in the near future. Whether on Earth or on manned space missions, its abundance in smaller quantities will generate significant stress and require adaptation to these new conditions. How the human species and ecosystems will adapt is a central question to be addressed.

Research objectives:

The objectives are to advance our understanding of the Earth's initial habitability conditions and how terrestrial geodynamic has influenced these conditions. The mains research objectives stand in better understanding:

1. the origin of water on Earth and other terrestrial planets
2. the conditions for the establishment of the first terrestrial continents and the role of terrestrial geodynamic evolution and geochemical cycle on the development and evolution of habitable conditions
3. the habitable conditions, stress and adaptability for an extraterrestrial future.

WP2.2 Temporal evolution of habitable conditions on Earth

Involved laboratories: LIEC, LSE, CREM, SIMPA, 2LPN, LOTERR, CEREFIGE, CRPG, GEORESSOURCES

Context: The pressures affecting the Earth's habitability are not systematically man-made. Throughout its whole history, our planet has evolved and sometimes generated constraints/forces that have affected its habitability. These changes can take the form of rapid and abrupt phenomena (*e.g.*, earthquakes, volcanic eruptions, landslides) as well as slower processes (climate change, global geodynamics, modification of bio-geochemical cycles). It is important to note that climatic variations can be both extremely rapid (*e.g.*, Little Ice Age) and long-lasting. These changes have had a profound effect on the Earth's biological history by impacting its biodiversity and forcing plant and animal species to evolve, which in turn has considerably modified the characteristics of its habitability at a given time. In addition to these pressures inherent in the functioning of our planet, the appearance and recent exponential growth of the human species has led to the development of new sources of stress for ecosystems. One characteristic of anthropogenic pressure is its ubiquitous and protean nature, which imposes significant (even lethal) stress on all living species.

The objectives of this task are to better understand the constraints exerted on habitable conditions and the stress generated on various ecosystems by (i) the bio-geochemical evolution of planet Earth over the course of its history (*i.e.*, decoupled from humans: climatic variations, seismic and/or volcanic episodes, tectonics, role of the ocean) and (ii) human societies and their lifestyles and how societies have been representing habitability in various socio, technological, economic, cultural and political dimensions. We will also focus on the influence of geological activities on human societies (*e.g.*, volcanic eruptions). The questions studied will aim to understand

- Climate variations on different time scales.
- Kinetics of eruption triggering in anthropized areas.
- Impact of anthropogenic stresses on ecosystems.

Stress ecology methods¹⁸ will be developed in this context. While several tools exist to assess the quality of an ecosystem and the main sources of alterations of biotic and abiotic components, we are currently not able to (i) precisely evaluate the health of organisms inhabiting ecosystems at various levels of perturbation (*i.e.*, by a contaminant, by thermal or anoxic stress, by species introduction) and (ii) to predict the modification of this health status under several scenarios of environmental changes and the consequences at the ecosystem levels. By combining approaches at several biological levels (from the individual to the ecosystem process), we aim at evaluating acclimation/adaptation abilities of biocenoses and the impacts on ecosystem services. Two main contexts can be considered: hydrological stress through the study of intermittent streams and contaminant-induced stress. Moreover, the expected deliverables are the production of (i) models of bio-geological crisis and how living species recovered, (ii) maps of habitable conditions in regions of the world at geological risk, (iii) models of effect propagation through biological levels and (iv) indicators of organisms' health status.

Research objectives: The objectives aim at understanding how external pressures, either natural or anthropic, have affected the terrestrial habitable conditions. The main research objectives stand in better quantifying:

1. the impact of geological processes on living ecosystems and human societies;
2. the stress generated by human societies on plant and animal species.

WP2.3 Lorraine by the end of the century: the Mosel River.

Involved laboratories: LIEC, LSE, IRENEE, CREM, SIMPA, 2LPN, LOTERR, CEREFIGE, CRPG, GEORESSOURCES, 2L2S, SILVA

Context: The Mosel River is the backbone of the Sillon Lorrain, with a long history of human presence. This river has been and still is an essential factor of societal development and economic activity. Indeed, it provides numerous environmental goods and services, from self-epuration mechanisms to energy supply through irrigation, shipping and drinking water supply. All of them need at least a sufficient quantity of water, and most of them also need a good quality. If these conditions are not fulfilled, a risk exists not only for the environment and local populations, but also at a larger scale, since the Mosel River is a crossing several borders, adding some geopolitical issues.

However, climate scenarios predict a decrease in water availability in the next decades associated to an increase in temporal variability of this availability, and a trend toward a decrease of flow rates, requiring a rethink of the extractivist logic that currently prevails towards water resources. In the meantime, contaminants discharge is not decreasing, eutrophication increases, especially in gravel pits used for recreational activities with cyanobacterial blooms, and climate change impairs the reservoir function of the Vosges mountains.

In this context, several main objectives have been identified. They cannot be addressed simultaneously, so a tier approach will be implemented. These objectives will immediately mobilize funding and human resources from the EPHeimeris project, this project will be progressively enriched through the different calls for projects.

Research objectives:

The first tasks will be dedicated to present time:

1. Identify and prioritize quantitative and qualitative pressures on the resource at river basin level and evaluate risk for ecosystem sustainability, in relation to backbone project 2.
2. Identify human activities that relies on water availability, quantify and characterize their needs (again, in terms of quantity and quality)
3. Identify expectations and concerns towards extreme events associated to water flow

A second step will be dedicated to an analyse of the trajectory, from geological times to the end of the 21th century, of water resources at the regional scale.

1. Identification of the main reservoirs, their hydrological functioning (filling dynamic), their state compared to several temporal references, the predictions under several climatic and economic scenarios, in relation to backbone projects 2.1 & 2.2.
2. Compute a risk analysis integrating ecological, economical, energetic, agricultural... risks, evaluate the cost associated to a limitation of water availability (still both in quantity and quality)

WP3 — Communication and mediation of habitability

The aim of this work-package is both to communicate the notions of **past, present and future** habitability, and to study the **different ways of transmitting and sharing work** on this concept with the various stakeholders, from scientists to political actors, from industrial actors to NGOs and citizens. A central element of the project will be the implementation of proactive communication and mediation approaches aimed at a wide audience, beyond the scope of traditional fundamental research projects, and drawing on a tradition of reflexivity specific to the epistemology of the human and social sciences and the humanities in general. Moreover, the exploration and implementation of innovative participatory science methods to encourage the dissemination and appropriation of project results are at the heart of the strategies of this work-package. These will particularly be aimed at three priority target audiences: (i) students and young adults; (ii) organized civil society actors (associations, lobbies, etc.); (iii) political decision-makers. To communicate and mediate changes, three major issues will thus be specifically addressed by this aspect of the project, with three major roadblocks specifically targeted by the project:

- the perception of long-term externalities from human-environment interactions at work within socio-ecosystems;
- the exploration of Western societies' representations of well-being, nature and acceptable habitable conditions;
- discourse and narratives regarding terrestrial and extra-terrestrial futures.

First, we will question the **difficult perception of habitability limits** constrained by immutable physical, chemical and biological processes, on which technologies cannot act. The integration of these constraints both within our “spaceship Earth” and within our planetary system often contradict the narrative of the “new frontier” and techno-scientific positivist discourses. These discourses may have led us to believe that engineering or scientific progress will, one day, absolve Human societies from the laws of nature. Exacerbated, these discourses can become ideologies that may, ultimately, be counter-productive and hinder the successful adaptation of our societies toward more sustainable habitats. For instance, this question could be addressed through the study of these discourses and narratives in different forms of scientific and non-scientific productions, from scientific vulgarisation to creative and cultural industries' different formats (arts, literature, graphic novel, audiovisual, videogames, etc.). This study will mobilize a wide range of discipline from social sciences to humanities as well as including other reflexion from liberal arts.

Secondly, the project will stress the necessity to reconsider **the place and importance of environmental health** as a key factor of “OneHealth” projects. Human health, at the heart of OneHealth approaches and discourses, should be considered as an objective but not as the pivotal lever for action. This weakness of consideration resulted in the development of EcoHealth concept, that concretely increased the fragmentation of research landscape between human and nature. Indeed, “environmental health” is too often perceived and considered as essential forcing variable, or summarized as the presence of contaminants that human activities have been disseminating (exposome), and that can impact human health. By bringing together the concept of exposome and all the effects - direct or indirect - this exposure to stress generates on fauna, flora and microorganisms in natural environments, EPHemeris wants to foster the redefinition of the concept of environmental health, thereby leading societies to a better understanding of their negative's externalities.

Finally, the project will question how to overcome the **negative perception of sustainable development solutions** toward future habitability. Indeed, especially in Western societies, most of the solutions proposed involve, at different levels, implementing some sort of sobriety, more or less radical, in our models of resource use, consumption and development. However, these solutions have been neglected because they are in contradiction with the socio-economic systems considered as a norm/dogma. The project will thus explore psychological and socio-technological-economical-ecological-political dimensions of lock-in effects associated with path dependency in our societal development models as well as propose mediations solutions that go beyond the classic “acceptability of change” model which often led to strengthening public resistance and polarizing opinions.

Ultimately, while exploring these issues, this work-package will aim toward the creation of a **Conference of Parties regarding habitability** bringing together all target audiences and hosted by UL. This “Habitability COP” will be launched in the last year of the projects, drawing on initial results from WP1’s Observatory of Habitability and WP2’s backbone projects. While helping us identify and bring together all interested parties, it also follows EPHemeris’s goal to adopt a reflexive perspective throughout the project by focusing on mediation and dissemination of results while integrating stakeholders in the scientific process and fostering participation. Several actions and events for our target audiences will help us prepare, accompany and strengthen EPHemeris’s network. For instance, students and young adults can be targeted through specific teaching modules which will allow to test and reinforce their knowledge as well as empower them to be actor of change. Pedagogical days will also be developed in order to exchange information and skills about existing training courses and those under development, with the whole academic community. Moreover, we will set up a cycle of seminars around the questions of habitability, specifically designed to actors in the associative, political and socio-economic sectors. EPHemeris will therefore be operated as an open project in order to allow a broad dynamic within many communities and gather new participants interested in the scientific, pedagogical and/or communication aspects. This will reinforce UL’s reputation as an integrated actor in the social fabric. In addition, the expected results will help develop specific communication material for the target audience, for instance, training kits for elected officials, managers, business leaders or NGOs representative with tools adapted to each person’s level of responsibility. This will also create a positive emulation toward the project and help reinforce the UL’s dynamic and participation in Sustainable Development Goals (SDGs) as well as identify UL as a key player regarding habitability. This COP will also serve both as the climax and conclusive event of EPHemeris as well as open the discussion and reflexion for further continuation of the project as a LUE program.

Research objectives:

Three main objectives are addressed within the scope of this work package:

1. the difficult perception of habitability limits;
2. the place and importance of environmental health;
3. the negative perception of sustainable development solutions.

The creation of a Conference Of Parties regarding habitability serves as a strong mediation and dissemination event of the project in addition to create a space for future research within the scope of EPHemeris key scientific and societal goals.

Relationship between workpackages and subprojects.

The relationships between sub-projects and workpackages, as well as the inputs/outputs linking sub-projects, are summarized in the **Fig. 4**.

Backbone projects within WP2 will produce independent deliverables, and deliverables that will feed the project 'Lorraine 2100'. WP1 will be based on both external information and practices developed in EPHemeris. Finally, strong dependencies will exist between WP2 and WP3, since the latter will propose strategies to communicate outside EPHemeris findings obtained in WP2.

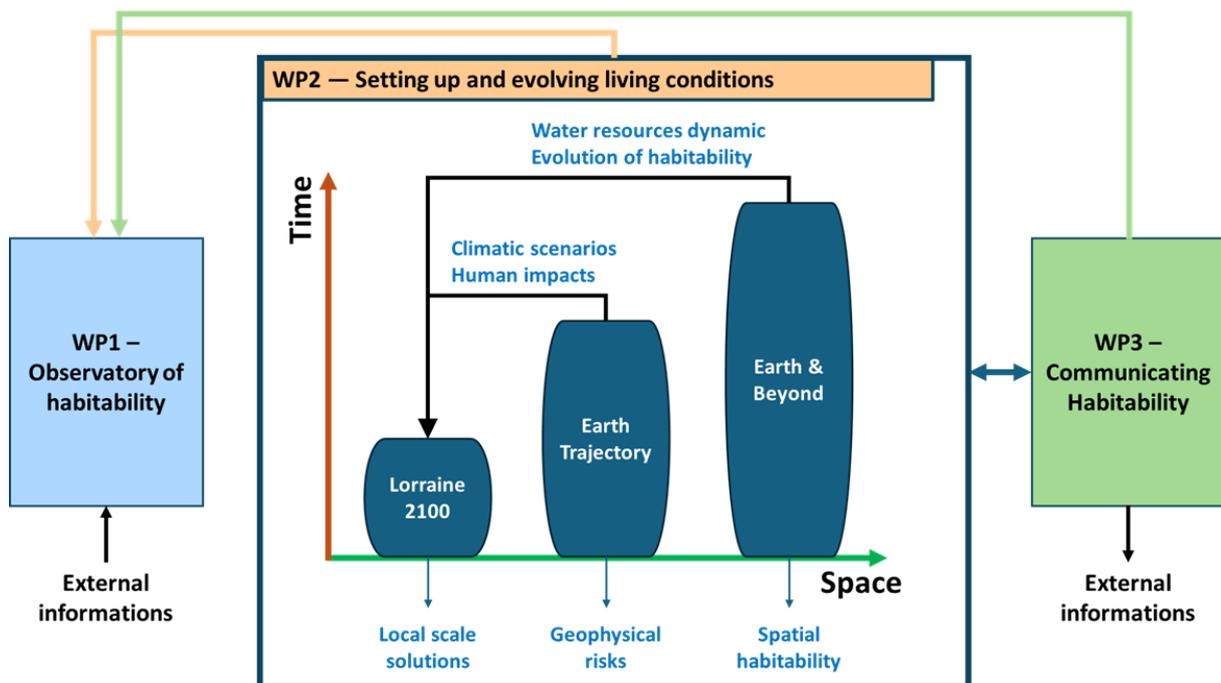


Fig. 4: Relationships between workpackages and projects.

Pre-existing multidisciplinary or interdisciplinary dynamics

EPHemeris is a newly designed project that has not yet had an operational existence within the framework of Lorraine Université d'Excellence (LUE). That said, the EPHemeris project results from the fusion of three projects previously proposed by different communities representing several laboratories and scientific poles of the Université de Lorraine. It should be noted that the decision to merge these projects was taken well before the procedure initiated by LUE to combine projects with thematic similarities. This attests not only the recognition of a common ambition by project leaders and their strong motivation to work together but also to the true interdisciplinary nature of EPHemeris.

EPHemeris aims to place the question of habitability at the heart of the scientific and training activities of the Université de Lorraine and integrating it into public consultation and debate alongside economic and political decision-makers. Importantly, the EPHemeris project will not only focus on

human societies but also encompasses ecosystems and their interactions. Only through interdisciplinary approaches can we fully grasp, quantify, educate about, and communicate the intricate processes shaping our planet, across global and local scales. We believe this approach is essential given the current climate change and its consequences on all forms of life. This far-reaching ambition is necessary if we are to enable the development of a human way of life that respects all living organisms and their respective environments.

While the project is new, the laboratories to which the 3 PI belongs (LIEC, CREM, CRPG) have previously worked together on interdisciplinary projects. For instance, researchers from LIEC and CREM (involved in the EPHEmeris project) have already developed the habitability-related PESTINTER project (ANSES), which is also the continuation of previous research dynamics (CLEURIE 2, funded by Zone Atelier Moselle) started in 2019. PESTINTER aims to evaluate the multiple effects (environmental and societal) of pesticide contamination of aquatic ecosystems, in the context of an interdisciplinary pilot site currently being set up: the Cleurie (Vosges, France). The objectives are to characterize: (i) the *in-situ* toxic pressure of pesticides, (ii) their effects on organisms that are indicators of water quality and (iii) the circulation of scientific knowledge produced between the different local actors. This project is representative of the interdisciplinary dynamic that underpins the creation of EPHEmeris, as researchers from various disciplines collaboratively endeavoured to co-create a tangible research object – pesticide contamination - centred around a specific territory: the Cleurie River. In addition, the analysis of communication and societal interactions, which was at the heart of the project's actors' concerns prompt us to also investigate the effects of researchers' activities in a territory. This also reflects a real concern for reflexivity in scientific practice from the beginning of the project. Thus, the interest in understanding how we build together a common object at the crossroads of disciplinary questions and distinct epistemology, paved the way for EPHEmeris and reinforced the conviction of the teams involved in the interest of an animation of a high-level scientific project.

Another joint project between CRPG and LIEC (funded within the framework of the LabEx R21) aims to better understand the occurrence, fate and transfer of lithium (and its isotope) in freshwater ecosystems. The boom in renewable and low-carbon energies as well as digital technologies is giving rise to a growing need for the strategic element that is lithium. It has numerous industrial applications, dominated since 2015 by the battery sector. The future multiplication of demand and inherent discharges will generate new pressure on water resources and their quality. It is paramount to understand the occurrence of lithium (natural and anthropogenic) and its isotopes in freshwater ecosystems and determine implications for the assessment of its environmental impact. To do so, a collaboration has been developed between the LIEC and the CRPG to develop chemical and isotopic imaging using ion probes in biological materials. This innovative development will make it possible to determine the distribution, accumulation and isotopic variations of Li in aquatic organisms. The determination and understanding of the lithium cycle following these interdisciplinary approaches (geochemistry, physico-chemistry, isotopy, ecotoxicology) in the different abiotic and biotic compartments located in natural geological environments or in anthropogenic environments rich in Li, is essential for (i) predict the potential risk associated with the transfer of Li from various mineralization's to biota and its potential biomagnification (ii) provide information for a better understanding of the anthropogenic impact of Li in areas of exploitation and industrial uses and (iii) improve the understanding of the biological mechanisms of Li toxicity through a Li isotope metallomic approach.

Beside these examples, the interdisciplinary is already at play in many other contexts, through either research programs funded by the Université de Lorraine Interdisciplinary Call (*i.e.*, Bain des Remparts), the Maison pour la Science (*i.e.*, Ecrire les Plantes) or through consortium merging chemistry, geology, communication studies, ecology, machine learning, for instance in the context of the Zone Atelier Moselle (ZAM) or the Observatoire Hommes-Milieus Pays de Bitche (OHM PdB, Labex DRIIHM). The ZAM studies socio-ecosystems through sociology, economy, ecology, pedology... to understand how the health of aquatic ecosystems affect the well-being of populations that use these ecosystems. All these projects attest the natural interdisciplinary nature of research within and between the three laboratories (and the 3 co-PIs) involved in the project.

Beyond this pre-existing dynamic, an infatuation for the project is at work, as evidenced by the first meetings organized over the past 6 months, with new colleagues, representing new scientific fields, joining the initial consortium. EPHemeris now gathers people from more than 10 laboratories from 5 Scientific Poles, with roughly 90 people involved (**full list in ANNEXE 1: List of people involved**).

Programmatic vision

EPHemeris while managing several core projects with the financial support from LUE, also aim to create a “leverage dynamic” to raise additional funds and explore other funding opportunities. Consequently, three different pathways will enable the consortium to develop innovative research:

1. Provide a conceptual framework to enrich questions that are already developed by the different partners in ongoing projects;
2. Provide financial support to either fill in gaps between approaches or add approaches in research projects already funded;
3. Start new projects that will allow to integrate (and ideally lead) larger consortium (PEPR, Europeans...).

To guarantee efficiency, rapid results and to structure the first research steps, the three backbone projects (WP2) will be set up at the start of the project. These three projects fall within the objects’ field outlined in the matrix (Fig. 2) and will further enrich the reflexive perspective at the core of our research agenda. They will enable us to refine our interdisciplinary objects following backbone projects’ progress and first results. In addition to these already funded projects, annual calls for projects will be dedicated to scientific and pedagogic proposals from year 1 to year 3. There will be no call for the final year of the project, allowing the project’s team ample time to evaluate, disseminate and promote its results. Interdisciplinary workshops involving the whole EPHemeris community will take place regularly to structure, communicate and energize the different approaches carried out within the project by the different work-packages.

Calls for proposals will be open to all scientific and training communities of the Université de Lorraine. EPHemeris will therefore be operated as an open project in order to allow a broad dynamic within many communities and gather new participants interested in the scientific, pedagogical and/or communication aspects.

Backbone sub-projects

Half of the total LUE funding will be dedicated to the backbones' projects. Their global aim is to propose a common playground, that will make easier to develop interdisciplinary approaches and allow innovative questions and methods to arise. These sub-projects should also lead to set up a *living lab*, where research-action is co-built with the diversity of stakeholders concerned especially in the Grand Est and will nourish partnerships and discussions toward the creation of a Conference of Parties regarding habitability. Moreover, a living lab is also a structure that allows testing solutions and novel practices for development of societies in a habitable world, thus fitting EPHemeris's goal to provide actionable scientific resources and to integrate dissemination and valorisation of research where it is most needed and closest to societies' needs.

Call for scientific and mediation proposals

Given the financial volume available for an impact project like EPHemeris, we propose to focus on medium-scale projects. These projects, funded to the tune of €10-25k over a period of 1 or 2 years, will enable dynamic research to be put in place, new ideas to emerge and give project leaders the opportunity to apply for larger-scale funding (*e.g.*, ANR). The idea is to fill an important gap in French research by promoting medium-sized and ambitious projects. While special attention will be given to interdisciplinary approaches, we also believe that relevant disciplinary projects should be funded as well. They will participate in the scientific dynamics of the project and will contribute to an interdisciplinary vision of habitability.

Priority will be given to proposals that will be linked to one of the work packages, and that propose to deepen a particular aspect that has been identified as essential by the scientific committee of EPHemeris. It could be either a methodological development, a field scale test for a stress-mitigation or adaptation method to make a proof of concept, produce preliminary results to strengthen a future proposal.

The scientific calls for tender will take place once a year, but we propose that researchers with a project that falls within the scope of the global project can submit it without a specific time frame in order to discuss it, possibly put them in contact with other researchers involved in EPHemeris and thus prepare them for the next scientific call. We propose that applications for funding should be based on (i) a relatively short written project (5 pages maximum), (ii) an oral presentation and (iii) a substantial period of discussion with the assessment committee. The evaluation committee will be made up of the project leaders and members of the EPHemeris steering committee.

Beside proposals dedicated to students, EPHemeris will also offer funding for the development of mediation tools (conference organisation, exhibitions, communication media for the general public...). Our objectives towards this specific public are detailed below (part 7). Laboratories in the consortium are, for most of them, trained to scientific mediation, and are already contacted by stakeholders to develop mediation tools (ie by Rhin-Meuse Water Agencies for an exhibition on OneHealth).

Call for pedagogic proposals

One of the aims of EPHemeris is to initiate new teaching units for the next pedagogic contract starting in 2029, and to implement within these units' innovative pedagogic strategies. However, considering the originality and the level of interdisciplinary we plan to develop, this pedagogic innovation has to be tested, and colleagues in charge of teaching have to be trained. Consequently, several calls for projects (from year 2 to 4, (**Fig. 5**) will be opened to propose new lectures, within the existing educational structures and devices at play in the Université de Lorraine.

However, since the actual structures may not be adapted to such development, EPHemeris will be open to summer school and researcher school proposals, that can allow to experiment in a more open environment.

Regarding calls for project, financial requests for the three backbone projects can be submitted throughout the year, as long as the dedicated budget is not totally engaged. For scientific, mediation and pedagogic proposals, a more formal yet light process will be set up, with defined periods for resource use. All these calls will be open to the entire academic community.

Project animation

Following EPHemeris structuration, the three work packages (Fig. 2) will be in charge of the scientific animation.

Interdisciplinary days involving the whole EPHemeris community will take place twice a year aimed at structuring, communicating and invigorating the different approaches carried out within the project. While not exhaustive or systematic in nature, these occasions offer opportunities to:

- Conduct pedagogy workshops to exchange information and skills regarding existing training courses and those under development
- set up open seminars, broader than the core consortium, around the questions of habitability.
- Present results, share methodology and develop new perspective on interdisciplinary emergence on the topic of habitability
- Share results, methodologies, and develop fresh perspectives on the interdisciplinary emergence on the topic of habitability.

The final event of EPHemeris will be the organization of a Conference Of Parties during the last year of the project. This COP will merge results obtained through the different baseline and side projects, and will:

- a. Present the diagnosis and solutions that have already been tested either on Lorraine territory or elsewhere, or that have never been implemented and need to be experimented.
- b. Identify the levers and means of action that can be mobilized as well as the obstacles and reluctance to implement these solutions (reluctance to change, scientist vision, discouragement, complexity, electoralism, short vs. long term, waiting for proof of concept, management of uncertainty, etc.).

- c. By combining that information, plan with the stakeholders actions to implement that allow maintaining human activities with the prevailing obligation to preserve the resources, and introduce the need for in-depth changes in our use of water resources.

The COP is planned as a three-days conference: the first day being exclusively dedicated to the academic community, and the following two days opened to all non-academic partners with which fruitful interactions have been established throughout the project, notably during the two-yearly seminars in 2026 and 2027. This conference will mark the project's conclusion and, ideally, lay the groundwork for its continuation as a LUE program over the next five years.

| Type | | 2025 | | 2026 | | 2027 | | 2028 | |
|---|---------------------------|--------------|---------------|---------------|---------------|---------------|---------------|--------------|----------|
| | | 1st sem. | 2nd sem. | 1st sem. | 2nd sem. | 1st sem. | 2nd sem. | 1st sem. | 2nd sem. |
| Backbone sub-projects | WP2 | BB-sb-call-1 | | BB-sb-Call-2 | | BB-sb-Call-3 | | BB-sb-Call-4 | |
| Call for scientific and mediation proposals | Call 1 year proj. All WP | | SMP-1Y_Call-1 | | SMP-1Y_Call-2 | | SMP-1Y_Call-3 | | |
| | Call 2 years proj. All WP | | | SMP-2Y_Call-1 | | SMP-2Y_Call-2 | | | |
| Call for pedagogic proposals | | | | PP_call-1 | | PP-call-2 | | PP-call-3 | |
| Project animation-WPO | kick-off meeting | 1 | | | | | | | |
| | EPHemeris days | | 1 | 1 | 1 | 1 | 1 | 1 | |
| | Seminar | | | | 1 | | 1 | | CoP |
| | COFIL | | 1 | | 1 | | 1 | | 1 |
| | Core team | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Fig. 5: Gantt chart for the EPHemeris project. Numbers in the grey cells indicates the number of meeting each semester for each kind of project animation.

Funding strategy

Our funding strategy, as outlined by the “Financial Gantt chart” bellow, first details how we propose to use the budget attributed to EPHemeris solely by LUE, and secondly our prospective according to (i) additional calls by other LUE funding tools and (ii) extra funding by external resources (Table I).

It’s important to mention that establishing a consolidated budget is challenging at that point. Indeed, several already funded projects in which EPHemeris members are already involved in, falls within the EPHemeris dynamic. One task of the WP1 (Observatory of habitability) will be to identify these projects in order to enlarge the amount of information available for WP2 and WP3.

| LUE request | | WP | 2025 (k€) | 2026 (k€) | 2027 (k€) | 2028 (k€) | Total (k€) |
|--|-------|-----|--------------|--------------|--------------|--------------|-------------|
| Backbone sub-projects | WP2 | | 120 | 80 | 100 | 60 | 360 |
| Call for scientific and mediation proposals | WP1 | | 10 | 5 | 5 | 10 | 335 |
| | WP2 | | 60 | 100 | 70 | 20 | |
| | WP3 | | 15 | 15 | 15 | 10 | |
| Call for pedagogic proposals | / | | | 15 | 20 | 15 | 50 |
| Project animation | WP0 | | 5 | 10 | 10 | 30 | 55 |
| Total (k€) | | | 210 | 225 | 220 | 145 | 800 |
| Other fundings | | | | | | | |
| LUE Post-Doc | WP1 | | | | | | 300 |
| | WP2 | | 75 | 75 | | | |
| | WP3 | | | | 75 | 75 | |
| LUE Doc | WP1 | | | | | | 120 |
| | WP2 | | | 40 | 40 | 40 | |
| | WP3 | | | | | | |
| Other sources (Regional and local authorities, ANR, Europe...) | WP1 | 200 | | | | | 460 |
| | WP2 | | | | | | |
| | WP3 | | | | | | |
| ANR (CPJ LIEC) | WP2-3 | | 200 | | | | |
| Water Agency - OneHealth mediation | WP3 | | 30 | 30 | | | |
| Total (k€) | | | 125 | 262 | 262 | 232 | 880 |
| Total Project (k€) | | | 335 | 487 | 482 | 377 | 1680 |

Table I. Financial Gantt chart: resource allocation within EPHemeris and expected complementary resources (amount and origin).

EPHemeris Budget

The funding will be mainly dedicated to functioning (field work, population survey, public event organization) and human resources. Concerning this last point, the ambition of EPHemeris is to give priority finance to Master 2. This choice is based on the very low support available today in French research for this kind of contract. We also believe that such research is of high risk for PhD students with short deadlines. The financing of post-doctoral students is another objective of EPHemeris, but will be possible only if additional funding can be obtained. Training post-doc is part of the objective to anchor research on habitability into the long-term research landscape, by preparing young researchers for university and CNRS recruitment.

A lower part of the funding will be dedicated to equipment since EPHemeris is not intended to provide significant support for new technological developments. However, in coherence with the

scientific core of the project, we will rather focus on the rejuvenation and maintenance of existing technical equipment in order to respect the principles of sustainable development. Instead of purchasing sometimes unnecessary new equipment, we aim to maintain existing analytical parks to the highest standards. Some equipment may also be necessary for field surveys, to monitor some parameters of interest.

A half of the EPHemeris budget will be dedicated to the three backbone projects that are, according to our matrix organization, transversal on the three identified WP. The budget is not the same for the 4 years, to encourage colleagues to start their project as soon as possible. As mentioned above, proposals can be submitted throughout the year. However, as the dedicated amount is defined, proposals arriving after the entire envelope has been allocated cannot be validated in year n , and will have to be switched to year $n+1$.

A second most important envelope is dedicated to the call for scientific and mediation proposal. WP1 and WP3 can appear under-funded, however, by experience, mediation and observation are essentially time consuming, and human resources are more crucial than functioning. Concerning WP1, calls can fund M2 internships or invitation of researchers leading groups and projects on similar topics to strengthen national and international partnerships. For WP3, funding can be used to develop projects with sub-contractors specialized in mediation, as well as produce mediation tools and materials. WP2 call for project will be usual, with a particular attention to inter- or trans-disciplinary dimension, and to the ability of deliverables to be used by a large community.

Call for pedagogic proposals, that are also more time than cost consuming, will start only on the second year of the project, since the main objective is to develop either virtual or concrete teaching units for 2028, when the next pedagogic agreement will be built. Complementary funding will be requested from dedicated programs (ORION, ExcellenceS, Eureka-Pro).

Finally, a part of the funding will be dedicated to project animation, with the EPHemeris days twice a year, and a larger event by the end of the project with the organization of a CoP over several days.

LUE tools

Since habitability is a highly transversal theme, we expect developing co-funding opportunities with other LUE interdisciplinary programs and projects. For instance, discussions with ARTEMIS interdisciplinary program proposal (Advanced Research and education on the biology, the Ecology, the Management and the biomonitoring of forest ecosystems in a changing world) highlighted numerous shared concepts and concerns with EPHemeris.

Besides those co-funding, EPHemeris will take advantage of the opportunities offered by the other LUE tools. A post-doc proposal focusing on risk management and titled "Habi(Li)ter - Co-defining the habitability of Lorraine under climate change and future multi-risk conditions" has already been submitted to the 2024 call. Another post-doc is planned to be submitted in 2026, preferably on WP3 topics (*i.e.*, on the perception of proposed solutions, or on the imaginary worlds around earth habitability in the future).

Furthermore, EPHemeris will apply for at least one doctoral funding opportunity in the international doctoral position call, once a partnership with an international counterpart of EPHemeris is established following the outcomes of WP1 – Habitability observatory.

External funding

This section is mostly prospective, as we cannot guarantee our future success to call for projects.

Firstly, a Junior Professor Chair at LIEC is planned for 2025 that will be associated to EPHemeris. Since the scientific profile (Durability Sciences) aligns perfectly with EPHemeris, the research activities associated with this CPJ along with the ANR's financial backing (200 k€), will offer additional funding opportunities for the project.

Simon Devin, an EPHemeris PI, has been contacted by the Rhin-Meuse water Agency (AERM) to spearhead an ambitious mediation project on OneHealth, with a minimal funding of 60 k€. Several PEPR (Priority Research Programs and Equipment) share common goals with EPHemeris, and we will be actively exploring funding opportunities for collaborative endeavors. Given the necessity for a territorial anchorage, we anticipate additional support from local collectivities, especially in the framework of the Lorraine 2100 backbone project. Finally, the first two years of the project will be dedicated to producing proof of concepts outcomes, enabling EPHemeris members to peruse fundings from national (EC2CO, MITI, ANR, ANSES...) as well as international (INTERREG, Horizon Europe, ERC) programs. The objective is to double the initial investment provided by LUE through external funding.

Training Objectives

Placing the concept of habitability and its challenges at the heart of our societies requires an interdisciplinary training approach. This cannot be achieved by focusing only on university-level education, but requires coordinated efforts across multiple levels to effectively reach society as a whole and foster widespread dissemination of knowledge as well as shared understanding of habitability and its challenges. Following the project goals, EPHemeris will therefore propose an integrated pedagogical approach dedicated to different public:

- academic training for young adults and future professionals;
- continuing education for professional actors, civil society leaders and key stakeholders;
- extramural and lifelong education for a larger public interested in the issue.

By training a diverse range of stakeholders who can later become “ambassadors” for our project, we aim to bolster UL's visibility and recognition of expertise regarding habitability.

Academic training

To equip future professionals with a comprehensive understanding of habitability, training programs must adopt an interdisciplinary approach, spanning from undergraduate to graduate courses, from bachelor to PhD. At each academic level, we will propose comprehensive and progressive pedagogic objectives. However, across all levels, two primary objectives will remain consistent:

- **Raise awareness about the issues of habitability** within the framework of fundamental disciplinary courses, included in knowledge and competence blocs, but

also through interdisciplinary modules. Mirroring the approach of SENSE modules, which aims to educate students about transitions' issues, EPHemeris's modules should concentrate on the pivotal aspects relevant to our projects (conditions of habitability; fragility and vulnerability of habitable conditions; Societies' and ecosystems' adaptability to changes).

- **Develop interdisciplinary modules** bringing together students and teachers from different training and theoretical backgrounds. These modules respond to several concerns of EPHemeris, starting with i) awareness of the complexity of habitability's issues which requires a multidisciplinary and holistic approach, as well as ii) the challenge of training a generation of future professionals and leaders capable of grasping these complex issues and, finally, iii) strengthen links between disciplinary communities within the UL.

For each academic level, we follow EPHemeris's ambition to associate "habitability" to the identity of UL. We believe that, regardless of the teaching level, individuals who have studied there should have the opportunity to be trained to these concepts. This would enable them to not only gain a keen scientific understanding of the issues but also a more meaningful comprehension of their impacts on our societies.

- **At Bachelor's level:** we plan to integrate content that is specific to disciplinary teachings and disciplinary competences. At the end of the project, we hope to offer original lectures tailored for the bachelor's degree within the unit "Sustainable Development and Social Responsibility" available for all students. This endeavour is designed to effectively equip future generations with the ability to grasp and incorporate this issue into their academic, civic and professional lives.
- **At Master's level:** our ambition is to develop at least one transversal unit that brings together students from various scientific fields, ranging from natural to social sciences, to catalyse knowledge sharing through collaborative work on specific topic, especially through learning-by-doing pedagogies. For instance, a hackathon addressing future water scarcity could be developed. A first teaching unit has already been set up to start in September 2024 (see below), with several others planned in the near future.
- **At PhD's level:** we will reach out the different doctoral schools associated to the research teams involved in the project to propose similar modules to those offered to master's students. These modules will be designed as transversal training that grant ECTS credits necessary for obtaining the doctorate. However, they could also be structured as two-day workshops to accommodate a larger number of students and facilitate an in-depth discussions and scientific output.

The following course and module descriptions are first suggestions and should be viewed as starting blocks and models for future courses and modules. These teaching units (TU) will evolve in response to the scientific advancements of the project and the emergence of new disciplinary collaborations within the scope of EPHemeris.

- **Starting in September 2024:** TU Habitability - 24h – STPE (Earth, Planetary and Environmental Sciences) of the Université de Lorraine faculty of Science and Technology. It will address the question of habitability *via* an interdisciplinary approach that intertwines geochemistry, geology, eco-toxicology and human sciences. This approach will train young students in the

basic concepts of habitability and the complex underlying controlling processes across several scientific fields.

- **To develop for 2029:** All the generic TU referring to habitability that can be proposed to students at the different education levels details above. As specified in the programmatic vision, our ambition is to develop and test the adequate format during the next 4 years, in order to be able to make a structured proposal to pedagogic teams, collegium and doctoral schools for the next accreditation. For instance, it can be an optional M2 TU of 30h, proposed to several master's degrees, aimed at developing interaction and communication skills with public and stakeholders. This TU could be associated to the Shift project, an initiative already proposed by Supelec Metz.

Continuing education

Another ambition of the EPHemeris project is to develop a continuing education program aimed at contributing to the ecological transition of the professional sector, both public and private. Following initiatives such as the "Territorial Scientific Council" which aim to train all public servants on issues pertaining to climate, resources and biodiversity, EPHemeris will develop modules open to professionals and relevant third parties interested in the habitability issue. The modules will have three main objectives:

- **Understand the complexity** of habitability, its conditions, the fragility and vulnerability of habitable conditions, and prepare societies and ecosystems for necessary changes.
- **Facilitate the appropriation** of concepts related to climate change and its consequences on the habitability of our planet and local territories
- **Encourage and guide** the rethinking of production objectives, tools and practices more compatible with sustainable development.

To reach these objectives, several axes and teaching units will be developed. These TU will also reinforce UL's notoriety as well as provide additional funding and resources opportunities.

Future development plans include a TU focused on habitability which will be developed at Ecole Nationale Supérieure de Géologie (ENSG) and Laboratoire Interdisciplinaire des Environnements Continentaux (LIEC) as part of the Junior Professor Chairs (CPJ) framework within these laboratories. This TU will be open to all engineering schools of Université de Lorraine, as well as to external individuals interested in learning about this topic (*e.g.*, teachers, industrialists, politicians). Another plan is to foster synergies with the national initiative for the training of state employees in ecological transition, given the similar overarching objectives. Several members of the EPHemeris community and scientific networks are already providing training in this project.

Extramural and lifelong education

In addition to initial and continuing education, we believe that EPHemeris can reach larger audiences and communities, especially within civil society and the beyond academic sphere. This educational goal is consistent with the purposes of the habitability COP we intend to launch by providing "laymen" access to scientifically sound knowledge necessary to take part in informed and equitable open forum, as well as contribute to the dissemination of UL's scientific production among

the general population. Furthermore, as we aim to open the project to public beyond the Grand Est region, we also seek to provide educational content to international audiences. Therefore, three formats are planned to be developed:

- **Virtual training.** A convenient way to render the concepts and tools developed in EPHemeris available to a wider audience, especially beyond Université de Lorraine, is to offer e-learning solutions. In collaboration with the Numeric Direction at the UL, and with the UVED (Virtual University Environment and Sustainable Development), we will produce virtual resources. The ideal format, that is easier to diffuse and guarantee a better appropriation by a large audience, consists of short videos, each lasting less than 5 minutes, organized in a scripted collection. To develop a coherent script, the production of video capsules can only begin in the project's second year, once sufficient progress has been made in the main work packages and relevant target audiences have been identified.
- **International training.** A module dedicated to international training could be proposed within the framework of the Eureka-Pro consortium of European universities on Responsible Consumption and Production, according to the opportunities provided by this system. The possibility of developing an Erasmus+ project will be discussed within the EPHemeris consortium. It could be a project co-built with students of different master's programs involved, aiming to enhance their appropriation of the European Teaching and Research Area. These opportunities will also help bringing together communities within academia that have diverse educational and theoretical backgrounds.
- **Lifelong education.** Retirement-age audience can contribute to societal change and accompany major shifts once provided with scientific data and a space to share and discuss knowledge with scientific actors. We aim to propose a series of conferences centred around habitability to several "University of the Third Age" or "University of Free Time" initiatives in Lorraine and the Great East region.

Synergies with strategic programs of Université de Lorraine

The EPHemeris project will be articulated with other instruments and strategic programs available at the Lorraine site. To support the development of research, training, and communication initiatives under under EPHemeris, several relevant instruments have been identified. Below, we give a brief overview of the Lorraine site programs and explain how we will mobilize these instruments to support EPHemeris's objectives.

1- ORION (Dare to Research during Training) — The aim of this program is to enable students to discover and practice research. It works to develop a community of students capable of meeting the challenges of tomorrow (conditions under which our planet can be inhabited is obviously a fundamental one). Within the framework of ORION, we identified several possibilities:

- Setting up a PhD student-researcher club to explore the concept of our planet's habitability, its complexity and how interdisciplinary research approach is necessary to tackle this challenge of the XXI century.
- Develop a 'critical thinking' teaching unit to discuss issues of habitability, how it is perceived by civil society, political and economic decision-makers and how it can be denigrated by lobbies.

- Apply for M2 Excellence grants to support students eager to pursue a PhD on issues relating to the habitability of our planet.
- Establish scientific events to showcase ongoing research to the society as a whole through scientific and entertaining events.

2- SIRIUS (Innovation Strategy for Strengthening University-Society Interactions) — The aim of this instrument is to increase the socio-economic impact of Université de Lorraine. We consider this instrument as important for developing EPHemeris as it will allow:

- creating networks with local companies, associations and authorities to collaborate on addressing the impacts of changes in terrestrial habitability conditions.

- enabling businesses and local authorities to understand the risks inherent to water quality and quantity degradation, especially in the framework of the backbone project: Lorraine by the end of the Century.

This instrument will also allow raising the profile of research in Lorraine by improving the visibility and the legibility of the EPHemeris project. To achieve this, we will conduct a press relations campaign through the SIRIUS instrument to (i) increase the visibility of EPHemeris through the media at regional, national and international level and (ii) facilitate contact with companies and local authorities interested in joining the EPHemeris project.

3- E&T (EDUCATION ET TERRITORIES) — This instrument aims at strengthening UL's reputation by taking action both internally on student training and externally in the regions. This project focuses on the transformation of the undergraduate level and on Science with and for Society (SAPS). The SAPS component aims to develop scientific mediation activities for secondary school pupils and students up to licence 3 (bachelor) level.

The concept of habitability and its implications primarily concern young and future generations. As such, they are a key audience that we must be able to reach. We believe E&T program could be particularly beneficial for the EPHemeris project regarding this aspect, in support of the WP3 – habitability communication. This will help us to structure and coordinate scientific outreach activities for schoolchildren - through the 'EPHemeris for Children' and students, as well as developing new initiatives throughout the region.

Objectives in term of innovation and interactions with society (Sciences Avec et Pour la Société – SAPS)

At the heart of the EPHemeris project is the elevation of habitability questions to the forefront of our societies, with a particular emphasis on the Grand Est territories. To do so, we will engage with existing research structures in which EPHemeris can bring its specificity (*e.g.*, ZAM, OHM PdB). Additionally, we will establish a living lab focused on water resource management, aiming at co-building strategies with users and stakeholders to ensure ecosystem services (storage, recreation, self-purification...) through restoration, pollution mitigation and rational use. This endeavour will be central to the CPJ "science of sustainability" that will open at the LIEC in 2025. This living lab will be a city-wide

experiment facilitating interactions among knowledge institutes, private actors, users and public actors on this critical theme to raise awareness of its complexity, make research products accessible, and develop concrete actions. Its structure and development will make it possible to overcome controversies and to establish consultations on this critical resource for maintaining habitability. This unique approach will educate and train individuals capable of understanding and developing an economy based on current ecological reality. It will also enable comparisons between the notions of technological innovation and deinnovation, both of which may bring valuable solutions.

This commitment to society will extend to addressing other pressing issues (*e.g.*, soil pollution, biodiversity crisis...) and will take various forms such as exhibitions and conferences for the general public, interventions in schools and teachings of modules in free-time universities and permanent culture. Regular events, such as “La fête de la Science” or “La semaine de la Recherche” in which several members of the consortium are already involved, will provide excellent opportunities to reach a broad and diverse audience. The overarching goal is for all societal actors to extensively interact on this central question in the decades to come. To achieve this, it is essential for us to be recognized as key players in the ecological transition at the territorial scale, enabling us to be associated in the discussions and reflections during the next regional conference of the parties (COP), in order to bring the topic of habitability to the forefront.

In addition to our strategy to engage all of society in addressing issues related to habitability, it is noteworthy to mention the emergence of a new structure: a regional climate expert group (the so-called "GREC" = groupe régional d'experts sur le climat). This group, currently being established in the Grand-Est + Alsace region under the impetus of the OTELo scientific pole, provides an additional avenue for interaction and collaboration. The GREC's role will be to centralize, transcribe and share scientific knowledge on climate and climate change in the northeast region. Its primary objective is to inform local managers and decision-makers (elected representatives and technicians from local authorities, protected areas, major facilities, etc.) so that scientific findings can be better understood and taken into account into public policy. Of note, several researchers involved in the EPHemeris project are actively contributing to the establishment and development of the northeast GREC.

Positioning within national and international landscapes and induced partnerships

The project EPHemeris will be established and developed in a very active national and international context. Several programs related to habitability are already underway in the Grand Est region (*e.g.*, Fédération Recherche Environnement et Durabilité, University of Strasbourg) and at the international level (*e.g.*, Follow the water, NASA). In addition, the European space strategy (co-piloted by CNES) is also based on the search for traces of life on the planet Mars and on the conditions of habitability of this planet for an extraterrestrial future of the human species. Furthermore, the French research community will be structured over the next 7 years by the PEPR (Priority Research Programs and Equipment). More than half of them have perimeters related to the questions of Earth and planetary habitability ([IRIMa](#), [Faicarbon](#), [OneWater](#), [BRIDGES](#), [Origins](#), [SOLUD-BIOD](#), [SOUSSol](#), [TRACCS](#), [TRANSFORM](#)) and will be privileged interlocutors for EPHemeris. In addition, the themes related to habitability are at the heart of the IPCC (Intergovernmental Panel on Climate Change) action. Several researchers involved in EPHemeris are already involved in the work of the IPCC and the

implementation of our project will only increase their number and thematic diversity. Finally, the importance of the questions of habitability is illustrated by the numerous conferences dedicated to this topic:

- [Habitabilité de la Terre et transitions justes. La question climatique](#)
- [Limites planétaires et enjeux de durabilité](#)
- [Rencontres des sciences de la durabilité](#)

A preliminary benchmark of research conducted on the concept of habitability was carried out within the framework of WP1 – the Habitability Observatory. We performed a bibliographical search on Web of Science using the query: habitability ± Earth ± planets. This approach enabled us to gain insights into (i) the universities and institutions already working on the concept of habitability worldwide (**Fig. 6A**) and a focus in France (**Fig. 6B**), (ii) the connections between these universities and institutions (**Fig. 6A** and **6B**), and (iii) the keywords associated with questions regarding the habitability of Earth and planets (**Fig. 6C**). From this preliminary research, it appears that the University of Lorraine is not seen as an important contributor to the questions (**Fig. 6A**) and has only limited interactions with other universities and institutions (**Fig. 6B**). EPHemeris thus appears timely and will position the University of Lorraine in a central theme of the years to come. Another interesting finding revealed by this bibliographic search is that research on habitability remains closely tied to the extraterrestrial concept and does not encompass research and scientific fields working in the area of Earth's habitability that do not explicitly mention it in their keywords (*e.g.*, Environmental sciences, Human and Social sciences). Although an interesting observation, this also shows the preliminary nature of the bibliographical search that should be performed with other keywords specifically used in the different scientific fields represented in EPHemeris. This will be done within the framework of the WP1 (Habitability observatory) and in close collaboration with the different researchers involved in the project.

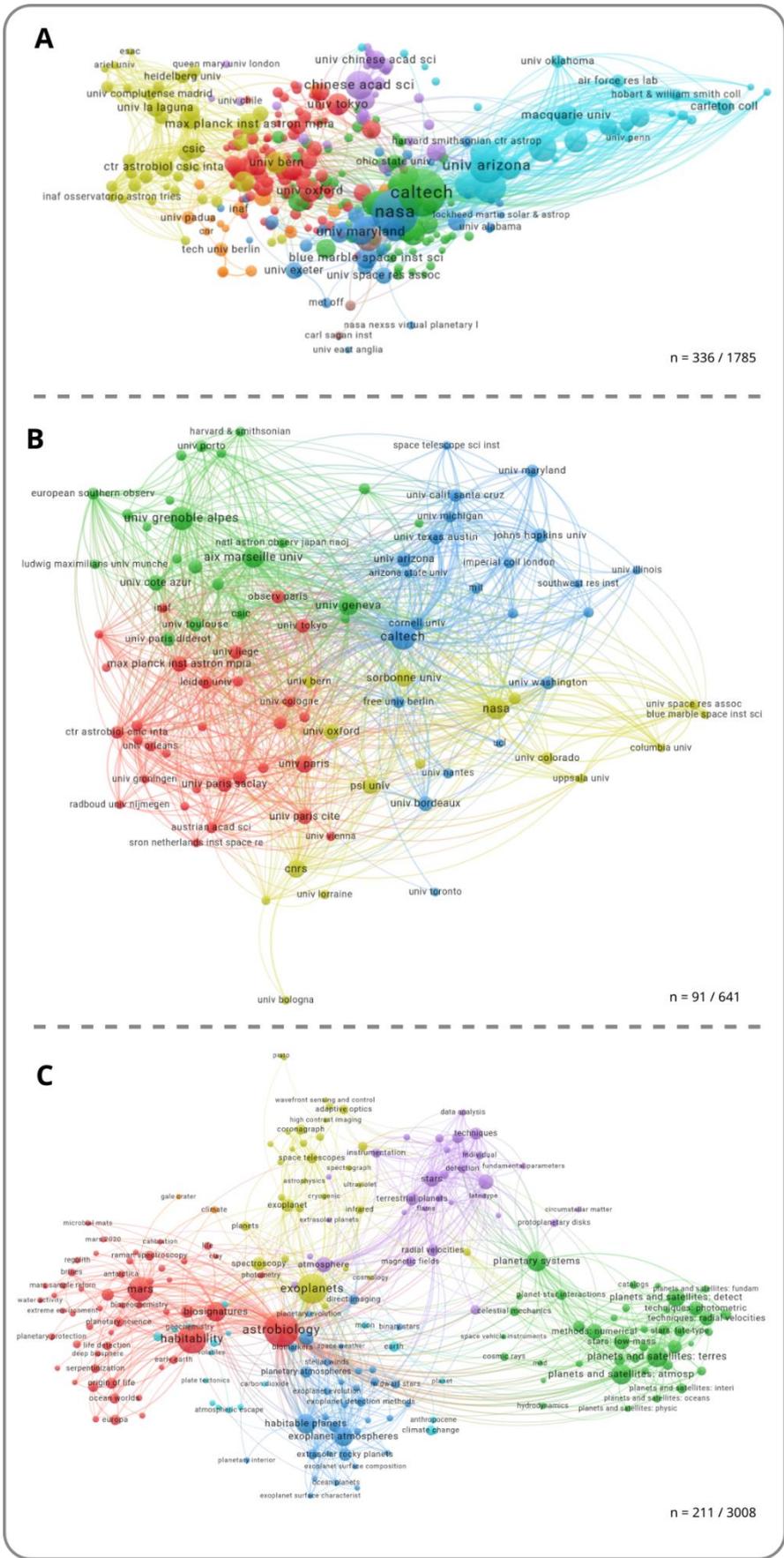


Fig. 6: The three figures result from an analysis of 1851 research articles spanning from 2020 to 2024, obtained from Web of Science by using the query: TOPIC = (earth or *planet*) AND (habitability or habitable). The figures illustrate (A) global research institutions and their collaboration network focusing on the concept of habitability, (B) a closer look at French research institutions and their collaboration networks, and (C) keywords associated with research on habitability. Clusters in 8A and 8B depict which research organisms are more likely to collaborate on writing a publication, while clusters in 8C indicate which keywords are more likely to be associated in publications. Only research institutions and keywords that reached the threshold of 5 publications were displayed (numbers noted “n=” in the figures)

One of the objectives of the EPHemeris project is to structure and federate the scientific and teaching communities of the Université de Lorraine involved in habitability research under a common banner. This structuring is fundamental to anchor and impact the Lorraine and regional ecosystem and to gain visibility at the national and international level. It will serve as a lever to (i) establish collaborations with other major projects addressing the issue of habitability (France, Europe, World), (ii) represent an important interlocutor with space agencies (ESA, NASA, JAXA), (iii) promote co-financing and the setting up of local (Grand Est region), national (ANR) and European (ERC) projects, and (iv) develop and fund new training courses and ways of teaching (ORION, ExcellenceS, Eureka-Pro).

However, beside the academic world, EPHemeris also needs to build and keep alive strong partnerships with the whole landscape of administrations that are concerned with the topics related to habitability (even if they not yet call it “habitability”). Water and soil resources management and is the main mission for national agencies such as ADEME, BRGM, CEREMA or OFB, but also for decentralised state services such as the Water Agencies. Researchers within EPHemeris are already implied on several projects co-built with them, and are already getting requested to develop evaluation or mediation tools for the next years. Apart from those structures, which are in fact already involved, the main challenge will be to gather local authorities and industries. For the latter, we are confident that the pole Hydreos will be the dedicated partner. For local authorities, discussions have already started with Nancy and the Eurométropole de Metz.

It is also important to note that the days of co-construction of the project led to a strong link with the sustainable development council of the Grand Nancy (C3D). This connection enables us to interact with people from civil society who actively contribute to the city’s daily life. In addition to opening up EPHemeris to civil society, it also helps to raise awareness of the project among the city's political decision-makers. To this end, a presentation of the EPHemeris project will be given in June to the C3D and elected representatives from Métropole du Grand Nancy.

Interdisciplinary potential and ability to gather a large community

Given that the concept of habitability is inherently interdisciplinary, the EPHemeris project will make an important effort to define and delineate its multiple facets, ensuring no one can feel unconcerned. With climate change underway and its consequences now visible in our daily lives, adopting a compartmentalized approach would be counterproductive for humanity. Understanding the ongoing and forthcoming impacts of these changes on ecosystems and human societies, and being able to propose concrete solutions, therefore requires an open approach without thematic restrictions. Though the core consortium is already large, EPHemeris will remain open to all sources of proposals and will endeavour to bring together different scientific approaches and training to build fundamental interdisciplinary solutions to these complex problems.

Our goal is thus to communicate (i) sciences of different horizons (human sciences, physical sciences, environmental sciences, material and process sciences) and (ii) bring together the different actors of society (associations, economic actors, political decision makers, teachers, trainers and researchers). The EPHemeris project will serve as a catalyst for these interactions to create spillover effects. Additionally, it will operate with openness, transparency and within the framework of open

science in order to (i) communicate researchers' daily actions to a wide audience, (ii) show the intricate complexity of the interactions at stake and (iii) lead to concrete co-constructed solutions with all stakeholders. Furthermore, EPHEmeris will remain open to the entire UL's community throughout its lifespan.

We would like to highlight the fantastic dynamic that has developed since the first days of discussion and co-construction of the EPHEmeris project. An inter-disciplinary community, eager to explore different scientific, training and communication approaches, has become involved in the project. Since the first meeting in October 2023, the EPHEmeris community has been growing, and now includes climatologists, geologists, eco-toxicologists, communication science specialists, stress specialists, geographers, soil scientists, hydrologists, urban planners, lawyers and economists. Each new discussion day sees new colleagues joining the project, fostering an ongoing interdisciplinary dynamic. What is particularly promising to us, is that colleagues seek a framework for conceptual reflection and fresh perspectives on their work. They come looking for more than just funds; they seek opportunities to overcome conceptual barriers or imbue their work with new significance.

Proposed Governance Structure

We propose to organize and manage the governance of the EPHEmeris project by setting up

1- A core team committee, responsible for overseeing implementation of actions, operational steering, day-to-day management, teams and consortium coordination. The core team will interact frequently to review projects submitted during the different calls and to guarantee the global objectives are well addressed by all the supported projects. This committee will comprise 7 members, including the three project co-leaders, three additional members yet to be determined, assisted by a project manager. Discussions are underway to include specialists in soil science, economics, and urban planning among these additional members.

2- A steering committee, which will convene annually to oversee the project's progress according to the establish plan. It will also provide recommendations and make any necessary or relevant changes of direction. Comprising up to 15 members, discussion is ongoing to identify individuals from diverse backgrounds, including: representatives from civil society institutions, heads of master's programs, stakeholders in business and in regional ecological transitions, private companies collaborating with Metz and Nancy, and secondary school teachers to bridge the gap between high school and university education (bac-3/bac+3). We are also willing to include representatives from the 5 UL's clusters involved in the EPHEmeris project: A2F, BMS, OTELo, SJPEG and CLCS.

Consistent with the methodology established since the beginning of the EPHEmeris project, it is important to highlight that, members of these two management bodies will be collectively chosen by the people involved in the project. Particular attention will be paid on ensuring diverse representation in terms of gender, scientific and pedagogical approaches, and professional roles (*i.e.*, researcher, technician, engineer). As part of this process, we will be holding a dedicated day to collectively setting up EPHEmeris project's governance on October 15th 2024.

CV of the CO-PIs of the EPHeimeris project

CO-PI #1 – Simon Devin

46 years old, Full Professor

Laboratoire Interdisciplinaire des Environnements Continentaux, UMR 7360 UL - CNRS

Campus Bridoux, Rue Claude Bernard, 57070 Metz

Email: simon.devin@univ-lorraine.fr

idHal: [simon-devin](https://hal.archives-ouvertes.fr/simon-devin) / ORCID: 0000-0003-4431-4987

Research topics

- Evaluation of anthropogenic stressors impacts on biodiversity and ecosystem health
- Effect propagation across temporal and spatial scales
- Development of interdisciplinarity in environmental assessment

Responsibilities

- Deputy director of LIEC (2018-2024)
- Manager of the Stress Ecology Team (2019-)
- Co-manager of the Water Treatment Efficiency axis of the Zone Atelier Moselle (2020-)
- Manager of the « Gestion des Milieux Aquatiques, Restauration et Conservation » master' course (2018-) and the « Gestion de l'Environnement » master' degree (2024 -).
- Appointed member of the Scientific Council of CNRS EC2CO program – AT DYCOVI (Contaminants dynamic and interaction with living organisms) (2017-2022)
- Vice-president of the Scientific Council of CNRS EC2CO program – AT DYCOVI (Contaminants dynamic and interaction with living organisms) (2023-2029)
- Appointed member of the Scientific Council of ADEME IMPACTS program (Impacts of interactions between pollutants on humans and the environment) (2021-)

Scientific production

64 publications in peer-reviewed journals and >100 communications (national & international)

~2150 citations, H-index 29

Two main publications of the last 5 years

Devin S., Potet M., Louis F., Pauly D., Rocher B., Wagner P., Giambérini L., Pain-Devin S. (2023). Spatial and seasonal use of biomarkers in Dreissenids: implications for biomonitoring. *Environmental Science and Pollution Research*. DOI: <https://doi.org/10.1007/s11356-023-28126-3>. Réf. HAL: [hal-04144488](https://hal.archives-ouvertes.fr/hal-04144488)

Oliveira C.*, Bouquerel J., Rochel X., Karimi-Moayed N., Vandenberghe D., De Grave J., Deforce K., Devin S., Robin V. (2022). Woodland Management as Major Energy Supply during the Early

Industrialization: A Multiproxy Analysis in the Northwest European Lowlands. *Land*, 11(4). DOI: <https://doi.org/10.3390/land11040555>. Réf. HAL: [hal-03636920](https://hal.archives-ouvertes.fr/hal-03636920)

CO-PI #2 – François Allard-Huver

37 years old, Associate Professor

Centre de Recherche sur les Médiations, EA 3476, UL

CLSH, 23 boulevard Albert 1er, 54001 NANCY

Email: francois.allard-huver@univ-lorraine.fr

Research topics

- Environmental and scientific controversies
- Scientific communication on sensitive issues (pesticides, GMO, food)
- Transparency in the public sphere

Responsibilities

- Co-Head of Research Group Praxis, CREM (since 2022)
- Elected board member, CREM
- General Secretary Académie des controverses et de la communication sensible (ACCS)
- Secretary of the Philosophy, Critique and Theory Division, International Communication Association

Scientific production

25 publications (chapters & journals) and 75 communications (national & international)

Two main publications of the last 5 years

1- **François Allard-Huver**. « Ce que les SIC font aux controverses environnementales, ce que les controverses environnementales font aux SIC ». *Revue française des sciences de l'information et de la communication*, 2021, *Environnement, nature et communication à l'ère de l'anthropocène*, 21, pp.[En ligne]. (10.4000/rfsic.10215). (hal-03142780)

2- **François Allard-Huver**. Knowledge, information and mediations in tension: A decade of food scandals and controversies. Bloomsbury. *Food Information, Communication and Education*, pp.87-102, 2022, 9781350162525. (10.5040/9781350162532.ch-006). (halshs-03788016)

CO-PI #3 - Yves Marrocchi

47 years old, Research director CNRS

Centre de Recherches Pétrographiques et Géochimiques, UMR 7358, UL, CNRS

15, rue Notre Dames des Pauvres - BP 20- 54501 Vandoeuvre-lès-Nancy

Tel: +33(0)3 83 59 42 27 - Email: yves.marrocchi@univ-lorraine.fr

Research topics

- Conditions and chronology of formation of the first solids of the solar system
- Dynamic of the protoplanetary disk
- Origin of chondritic and terrestrial water

Responsibilities

- Deputy director of CRPG (2020-2025)
- Cosmochemistry group manager at CRPG (2011-2020)
- Member of the Scientific Council of the National Planetology Program (INSU-CNRS, 2014-2023)
- Associate editor at *Meteoritics and Planetary Science* and *Geochimica et Cosmochimica Acta*

Scientific production

108 publications in peer-reviewed journals (~3300 citations, H-index 34)

Two main publications of the last 5 years

1- Piani L., **Marrocchi Y.**, Rigaudier T., Vacher L.G., Thomassin D. & Marty B. (2020) Earth's water may have been inherited from material similar to enstatite chondrite meteorites. *Science* 369, 1110-1113.

2- **Marrocchi Y.**, Villeneuve J., Jacquet E., Piralla M. & Chaussidon M. (2019) Rapid condensation of the first Solar System solids. *Proceeding of the National Academy of Sciences* 116, 23461-23466

References

1. Folke, C. *et al.* Our future in the Anthropocene biosphere. *Ambio* **50**, 834–869 (2021).
2. Bai, X. *et al.* Plausible and desirable futures in the Anthropocene: A new research agenda. *Glob. Environ. Change* **39**, 351–362 (2016).
3. Brook, B. W., Ellis, E. C., Perring, M. P., Mackay, A. W. & Blomqvist, L. Does the terrestrial biosphere have planetary tipping points? *TRENDS Ecol. Evol.* **28**, 396–401 (2013).
4. Steffen, W. *et al.* Planetary boundaries: Guiding human development on a changing planet. *Science* **347**, 1259855 (2015).
5. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: A Framework For Assessment*. (Island Press, Washington, DC, 2003).
6. Piani, L. *et al.* Earth's water may have been inherited from material similar to enstatite chondrite meteorites. *Science* **369**, 1110–1113 (2020).
7. Gaillard, F. *et al.* The Diverse Planetary Ingassing/Outgassing Paths Produced over Billions of Years of Magmatic Activity. *Space Sci. Rev.* **217**, 22 (2021).
8. le Polain de Waroux, Y. *et al.* How do we study resilience? A systematic review. *People Nat.* **6**, 474–489 (2024).
9. Dai, L., Vorselen, D., Korolev, K. S. & Gore, J. Generic Indicators for Loss of Resilience Before a Tipping Point Leading to Population Collapse. *Science* **336**, 1175–1177 (2012).
10. De Angeli, S. *et al.* A multi-hazard framework for spatial-temporal impact analysis. *Int. J. Disaster Risk Reduct.* **73**, 102829 (2022).

11. Angelstam, P. *et al.* Solving Problems in Social–Ecological Systems: Definition, Practice and Barriers of Transdisciplinary Research. *AMBIO* **42**, 254–265 (2013).
12. Brandt, P. *et al.* A review of transdisciplinary research in sustainability science. *Ecol. Econ.* **92**, 1–15 (2013).
13. Riviere-Honegger, A., Cottet, M. & Morandi, B. *Connaître les perceptions et les représentations : quels apports pour la gestion des milieux aquatiques ?* (ONEMA, 2015).
14. Devin, S., Felten, V., Pain-Devin, S., Gross, E. M. & Laviale, M. Alors, elle est polluée ma rivière ? Enjeux et opportunités de l’expertise scientifique interdisciplinaire. in *Proceedings of Science&You 2021 Parallel sessions* vol. 1 681 (Metz, 2021).
15. Albert, J. S. *et al.* Scientists’ warning to humanity on the freshwater biodiversity crisis. *Ambio* **50**, 85–94 (2021).
16. Holling, C. S. Resilience and Stability of Ecological Systems. *Annu. Rev. Ecol. Syst.* **4**, 1–23 (1973).
17. Peterson, L. D. *et al.* The H content of aubrites: An evaluation of bulk versus in situ methods for quantifying water in meteorites. *Earth Planet. Sci. Lett.* **620**, 118341 (2023).
18. Van Straalen, N. M. Ecotoxicology becomes stress ecology. *Environ. Sci. Technol.* **37**, 324A-330A (2003).
19. Allard-Huver, F. & Stein, M. La concertation citoyenne en environnement. in *Les Enjeux de l’information et de la communication, La concertation citoyenne en environnement*, 23 (2), 5-14. (2022).
20. Libaert, T. *Des vents porteurs : Comment mobiliser (enfin) pour la planète.* le Pommier. (2020).
21. Carlino, V., & Stein, M. (Éds.). *Les paroles militantes dans les controverses environnementales.* PUN-Editions universitaires de Lorraine. (2019).
22. Callon, M., Lascoumes, P., & Barthe, Y. *Agir dans un monde incertain : Essai sur la démocratie technique.* Editions du Seuil.(2001).

ANNEXE 1: List of people involved

| First and last name | Research unit | Team | UL's scientific cluster | Grade / role |
|-------------------------|--------------------------------|---|-------------------------|---|
| Catherine Thouvenin | C3D | / | / | Member of Nancy's Sustainable Development Council |
| Clémentine Payo | CNRS | / | / | Climat Biodiversity and Resources project officer |
| Elodie Andre | Univresity Partnerships Office | / | / | Partnership development officers within the partnerships department of Université de Lorraine |
| Jérémie Bel | LUE | / | / | Project manager |
| Guillain Mauviel | Ecological Transition Office | / | / | Vice-president of Ecological Transition of Université de Lorraine |
| Nicolas Brucker | MSH Lorraine | / | / | MSH Lorraine Director |
| Silvia De Angeli | Università di Genova | (Department of Civil, Chemical and Environmental Engineering) | / | Post-doc |
| Fabienne Barataud | ASTER | / | A2F | Research engineer |
| Stephane Uroz | IAM | Ecogenomic of interactions | A2F | Research director |
| Cyrille Rathgeber | Silva | EcoSilva | A2F | Research fellow |
| Aurelie Van-hoye | INSPIIRE | Modes de vie favorables et promotion de la santé | BMS | Assitant professor |
| Marion Trousselard | INSPIIRE | | BMS | Professor |
| Jean-pol Frippiat | SIMPA | / | BMS | Professor |
| Fabien Hein | 2L2S | | CLCS | Assistant professor |
| Anne Pignault | 2LPN | | CLCS | Professor |
| Benoit Bolmont | 2LPN | | CLCS | Professor |
| Christophe Luxembourger | 2LPN | | CLCS | Assistant professor |
| Jean-philippe Hainaut | 2LPN | | CLCS | Assistant professor |
| Angeliki Monnier | CREM | Pixel | CLCS | Professor and CREM director |
| Audrey Knauf | CREM | Pixel | CLCS | Assistant professor |
| Anne Piponnier | CREM | Praxis | CLCS | Professor (emeritus) |
| Emmanuelle Simon | CREM | Praxis | CLCS | Assistant professor |
| Julie Brusq | CREM | Praxis | CLCS | Assistant professor |
| Mouna El Gaied | CREM | Praxis | CLCS | Assistant professor |
| Francois Allard-Huver | CREM | Praxis | CLCS | Assistant professor |

| | | | | |
|--------------|------|--------|------|-------------|
| Johanne Same | CREM | Praxis | CLCS | Post-doc |
| Lucile Jean | CREM | Praxis | CLCS | PhD Student |

| First and last name | Research unit | Team | UL's scientific cluster | Grade / rôle |
|----------------------------|----------------------|--|--------------------------------|------------------------|
| Didier Francois | LOTERR | / | LLECT | Research engineer |
| Michel Caltagirone | LOTERR | / | LLECT | Research technician |
| Benoit Losson | LOTERR | Eaux et milieux | LLECT | Assistant professor |
| Claire Delus | LOTERR | Eaux et milieux | LLECT | Assistant professor |
| Gilles Drogue | LOTERR | Eaux et milieux | LLECT | Professor |
| Vincent Ollive | LOTERR | Eaux et milieux | LLECT | Assistant professor |
| Stephane Cordier | LOTERR | Transition Paysagères et Territoriales | LLECT | Professor |
| Vincent Bertrand | LOTERR | Transition Paysagères et Territoriales | LLECT | Assistant professor |
| Carole Wernert | LOTERR | Transitions, Acteurs et Aménagements | LLECT | Assistant professor |
| Nassima Hassani | LOTERR | Eaux et milieux | LLECT | Post-doc |
| Camille Cartier | CRPG | Cosmochimie et planétologie | OTELO | Assistant professor |
| Evelyn Furi | CRPG | Cosmochimie et planétologie | OTELO | Assistant professor |
| Francois Faure | CRPG | Cosmochimie et planétologie | OTELO | Proffesor |
| Guillaume Caro | CRPG | Cosmochimie et planétologie | OTELO | Research fellow |
| Jessy Flahaut | CRPG | Cosmochimie et planétologie | OTELO | Research fellow |
| Laurette Piani | CRPG | Cosmochimie et planétologie | OTELO | Research fellow |
| Marine Paquet | CRPG | Cosmochimie et planétologie | OTELO | Research fellow |
| Christophe Cloquet | CRPG | CYCLA | OTELO | Research engineer |
| David Bekaert | CRPG | CYCLA | OTELO | Junior professor chair |
| Gabriel Fénisse | CRPG | CYCLA | OTELO | PhD Student |
| Guillaume Paris | CRPG | CYCLA | OTELO | Research fellow |
| Pierre Bouilhol | CRPG | CYCLA | OTELO | Assistant professor |
| Pierre-Henri Blard | CRPG | CYCLA | OTELO | Research director |

| Sune Nielsen | CRPG | CYCLA | OTELO | Research director |
|--------------------------------|----------------------|--|--------------------------------|---|
| Veronique Le Roux | CRPG | CYCLA | OTELO | Professor |
| First and last name | Research unit | Team | UL's scientific cluster | Grade / role |
| Yves Marrocchi | CRPG | CYCLA | OTELO | Research fellow |
| Beatrice Luais | CRPG | Magmas et fluides profonds | OTELO | Research fellow |
| Lydéric France | CRPG | Magmas et fluides profonds | OTELO | Assistant professor |
| Raphael Pik | CRPG | Magmas et fluides profonds | OTELO | Research director and OTELO scientific cluster director |
| Jérôme Lave | CRPG | Tectonique, Érosion et Évolution du Relief | OTELO | Research director |
| Mary Ford | CRPG | Tectonique, Érosion et Évolution du Relief | OTELO | Professor |
| Michel Champenois | CRPG | / | OTELO | Design engineer |
| Anne-Sylvie Andre-Meyer | GeoRessources | GEM | OTELO | Professor |
| Antonin Richard | GeoRessources | GEM | OTELO | Assistant professor |
| Julien Mercadier | GeoRessources | GEM | OTELO | Research fellow |
| Yann Gunzburger | GeoRessources | GOR | OTELO | Professor |
| Raymond Michels | GeoRessources | GRÉSTOCK | OTELO | Research fellow |
| Vincent Huault | GeoRessources | GRÉSTOCK | OTELO | Assistant professor |
| Yves Geraud | GeoRessources | GRÉSTOCK | OTELO | Professor |
| Pauline Collon | GeoRessources | RING | OTELO | Professor |
| Cecilia Klespert | LIEC | / | OTELO | Assistant engineer - Communication manager |
| Marie Zaffino | LIEC | / | OTELO | Assistant engineer |
| Alexis De Junet | LIEC | CYBLES | OTELO | Assistant professor |
| Emmanuelle Montarges-Pelletier | LIEC | CYBLES | OTELO | Research director |
| Florence Maunoury-Danger | LIEC | CYBLES | OTELO | Assistant professor |
| Manuel Pelletier | LIEC | CYBLES | OTELO | Research Engineer |
| Pierre Faure-Catteloin | LIEC | CYBLES | OTELO | Professor |
| Sylvie Dousset | LIEC | CYBLES | OTELO | Professor |
| Vincent Robin | LIEC | CYBLES | OTELO | Assistant professor |
| Chloé De vernisy | LIEC | ECOSE | OTELO | PhD Student |
| Fabrice Teletchea | LIEC | EcoSE | OTELO | Assistant professor |
| Martin Laviale | LIEC | ECOSE | OTELO | Assistant professor |
| Simon Devin | LIEC | ECOSE | OTELO | Professor |
| Vincent Felten | LIEC | ECOSE | OTELO | Assistant professor |
| Aurelie Cebron | LIEC | EMMA | OTELO | Research fellow |
| Michael Danger | LIEC | EMMA | OTELO | Assistant professor |

| Angelina Razafitianamaharavo | LIEC | PhySI | OTELO | Research Engineer |
|------------------------------|----------------------|--|--------------------------------|---------------------|
| Céline Caillet | LIEC | PhySI | OTELO | Research Engineer |
| First and last name | Research unit | Team | UL's scientific cluster | Grade / role |
| Davide Vignati | LIEC | TEV | OTELO | Research fellow |
| Adeline Bouchard | LSE | / | OTELO | Research technician |
| Arnaud Herbreteau | LSE | / | OTELO | PhD Student |
| Noele Enjelvin | LSE | / | OTELO | Design engineer |
| Thibault Sterckeman | LSE | / | OTELO | Research engineer |
| Catherine Sirguy | LSE | / | OTELO | Assistant professor |
| Geoffroy Séré | LSE | / | OTELO | Professor |
| Marie-Pierre Dussine | CEREFIGE | Innovations et Dynamiques Entrepreneuriales - IDE | SJPEG | Assistant professor |
| Katia Blairon | IRENEE | | SJPEG | Professor |
| Cécile Fries | LHAC | | | Assistant professor |