RESEARCH CENTRE

Grenoble - Rhône-Alpes

IN PARTNERSHIP WITH:

CNRS, Université de Grenoble Alpes

2021 ACTIVITY REPORT

Project-Team STEEP

Sustainability transition, environment, economy and local policy

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

DOMAIN

Digital Health, Biology and Earth

THEME

Earth, Environmental and Energy Sciences

Contents

Project-Team STEEP

Creation of the Project-Team: 2015 December 01

Keywords

Computer sciences and digital sciences

A3.3.2. – Data mining

A6.1. – Methods in mathematical modeling

A9.6. – Decision support

Other research topics and application domains

B3.1. – Sustainable development

B3.1.1. – Resource management

B3.4. – Risks

B3.4.3. – Pollution

B3.5. – Agronomy

B4.1. – Fossile energy production (oil, gas)

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B4.5. – Energy consumption

B7. – Transport and logistics

B8.3. – Urbanism and urban planning

B8.5.1. – Participative democracy

B8.5.3. – Collaborative economy

B9.9. – Ethics

B9.11. – Risk management

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2 Overall objectives

2.1 Overview

STEEP started in January 2010, initially as an Inria "Action Exploratoire" (2010+2011). It is now an "Équipe-Projet Inria", located at the Inria Grenoble – Rhône-Alpes research center, and is also affiliated with the Jean Kuntzmann laboratory of the University Grenoble Alps (LJK).

STEEP (Sustainability, Transition, Environment, biophysical Economics and local Policies) is an interdisciplinary research team dedicated to systemic modeling and simulation of the interactions between environmental, economic and social factors. The aim is to better understand the biophysical trajectories and sociotechnical alternatives of our societies.

The work of STEEP follows research directions (see section 3) that cover different application domains (section 4).

2.2 Sustainable development: issues and research opportunities

Environmental issues now pose a threat to human civilization worldwide. They range from falling water tables to eroding soils, expanding deserts, biodiversity loss, rising temperatures, *etc.* For example, half the world's population lives in countries where water tables are falling as aquifers are being depleted. Roughly a third of the world's cropland is losing topsoil at an excessive rate. Glaciers are melting in all of the world's major mountains. The consequences on the present human societies are critical; they comprise for example a decreasing food security, significant population movements (such as climate refugees) and explosive geopolitical tensions.

Sustainable development is often formulated in terms of a required balance between its environmental, economic and social dimensions, but in practice public policies addressing sustainability issues are dominantly oriented towards environment management in Western countries. This approach is problematic to some extent as environmental problems and sustainability issues result from socio-economic phenomena (for example the economic growth model which is fueled by powerful and polluting technologies). Environmental problems have only recently been the object of media attention and public awareness. Most efforts bear on developing technological solutions. However, it is now clear that this will not be sufficient. We need to rethink our socio-economic and institutional models in order to leave room for a possible paradigm shift. In this perspective, we believe that crucial steps should be taken in research to help elaborating and implementing socio-economic alternatives.

The risks associated with delayed reaction and adaptation times make the situation urgent. Delayed reactions significantly increase the probability of overshoot of the planet carrying capacity followed by uncontrolled and irreversible evolution on a number of fronts. This systemic problem is amplified by two facts: the environment is degrading on all fronts at the same time, and at the global planetary scale, a first in human history.

Although environmental challenges are monitored worldwide, the search for appropriate lines of actions must nevertheless take place at all levels, in particular at local scales. At such scales, the proximity and smaller number of stakeholders allow decision makers to reach a consensus much more easily than at national or international scales. The failure of the 2009 Copenhagen summit and the small effective impact of the 2015 Paris Agreement are a good illustration of the difficulties encountered in international

negotiations. There are significant possibilities for operations at local scales, and the emergency of the situation gives the "think locally to act globally" logic an essential opportunity.

As of now, local decision levels have real political and economic leverage, and are more and more proactive on sustainability issues, either independently or in coordination through nationwide or European networks (we can refer for example to the European GMO-free Regions Network or to the Network of European Regions for a Competitive and Sustainable TouRism). Also, we think that two local scales are going to be increasingly dominant in the near future: urban areas (more exactly the employment catchment areas of main cities) and "regions" (such as Régions in France, Länder in Germany or Cantons in Switzerland). In particular, the sustainability of urban areas is one of the key issues of this century. As focal points of human activity, urban areas concentrate and amplify environmental pressures in a direct or indirect way.

Urbanization is a global and an ever-increasing trend process, with now more than half the human population living in cities. Although urbanized areas still represent a very small fraction of the total terrestrial surface, urban resource consumption amounts to three quarters of the annual total in energy, water, building materials, agricultural products etc., and pollution and waste management is a growing concern for urban planners worldwide. In France, for example, even if resource intensity (materials use divided by GDP [1]) has been reduced by half since the 70s, the actual material use (total and per inhabitant) has remained essentially constant, and household wastes have grown by 20% since 1995. Greenhouse gas (GHG) emissions have been reduced by a few percent since 1990, but the transportation share (a major issue on this front) has been steadily growing over the same period.

Furthermore, urban sprawl is a ubiquitous phenomenon showing no sign of slackening yet, even in countries where rural depopulation has long been stabilized. Urban sprawl in industrialized countries is largely driven by residential suburban growth. This phenomenon has both social and environmental consequences. First it implies an increase of daily mobility. In a context of high dependency on private cars and uncertainty on energy prices, this translates into an increased vulnerability of some population categories. It also induces an increase in greenhouse gas emissions, as well as an irreversible loss of cropland and a fragmentation of ecological habitat, with negative effects on biodiversity. The increasing concerns about climate change and upheaval in the market price of fossil fuels raise many questions about urban energy consumption while reviving the debate on the desirable urban structures and their determinants. Controlling urban sprawl is therefore a key sustainability issue.

Let us mention here that cities cannot be sustainable by themselves and that from this point of view, it does not make sense to focus on the municipality scale ("*communes*"). We think that it is very important to work at larger scales, typically, at employment catchment areas complemented by the adjacent agricultural and natural zones they are dependent on (that would correspond to the smallest scale for which a systemic analysis could make sense). Nevertheless, let us emphasize that because of resource imports and waste exports (e.g. GHG emissions), for any limited territory, the considered area will always depend on and impact other more or less distant territories. This is one of the key issues when trying to assess local sustainability.

Finally, let us note that the numerous and interrelated pressures exerted by human activities on the environment make the identification of sustainable development pathways arduous in a context of complex and sometimes conflicting stakeholders and socio-ecological interactions. This is why we also think that it is crucial to develop interdisciplinary and integrated approaches; consequently, our proposal tries to address the entire spectrum from scientific expertise to stakeholder decision-help.

3 Research program

After a first cycle of works since the creation of the team, we restructured our research program in 2019. It is now organized in two axes – Global Systemic Risks and Sociotechnical Alternatives – described in the following.

[1] Gross Domestic Product (GDP) is defined as an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production.

3.1 Global Systemic Risks

The objective of this axis is to develop methodologies and tools for estimating global systemic risks, as well as elements of strategic analysis for mitigating or adapting to these risks for public and private use. Global risks are related to environmental problems and their connections with and between many sectors of human activity and to different economic, societal and (geo)political dynamics.

Context Modern societies are characterized by a very high level of interconnections between numerous sectors, notably economic, social and geo-political ones, as well as by the environmental impacts of human activity and their negative consequences for societies themselves. These generalized interconnections, as well as the links between human activity and environmental destruction, carry intrinsic risks, known as systemic risks, because of the feedbacks present between all the parts of the global socio-environmental system.

These risks represent serious threats for modern societies, and the problems of collapse are part of the field of incurred risks. The question of systemic risks is important in the framework of the STEEP team's project, the core of which concerns sustainability issues at different spatial scales. The capacity of territories, states, the international community and the private sector to deal with this type of risk is one of the central elements conditioning this sustainability, but which until now has remained outside the team's scientific field of activity.

The literature devoted to systemic risks is important, whether it be modelling from the hard sciences (see for example [45] and [41]), or analysis from the social sciences (see for example [37]). However, for the moment, entire categories of risk remain little or not modeled in a systemic perspective, and moreover, in the human sciences, the historical and socio-political reading grids remain partially if not largely independent, despite the complementarities of these two approaches.

In the academic world, several institutes are interested in global systemic risks, with a strong component in the human sciences, or even an exclusive representation depending on the institute. The most representative of these are probably the Princeton Global Systemic Risk Institute, the Cambridge Center for Risk Studies, and the Risk Center at the ETH in Zurich. Various teams are also active on these themes, but often from a more sectoral perspective.

Five main categories of risk can be identified: economic, geopolitical, environmental, societal and technological. In the economic sector, the main risks are related to market instabilities, particularly in the energy sector, and financial risks. Geopolitical risks are largely related to potential sources of conflict, whether or not linked to the threat of terrorism. On the environmental front, climate change, loss of biodiversity and their consequences appear to be dominant, but natural disasters can also play a role; issues related to changes in land use (deforestation, erosion and desertification, artificialization) are also very important. At the societal or socio-political level, issues of inequality, food security, access to water, health risks (particularly pandemics) and migration are prominent. As for technological risks, they largely concern the fragility of modern computerized communication systems and network infrastructures (e.g. electricity distribution networks). These categories of risk and their interactions are represented in Fig. 1.

From the point of view of the broad categories of processes involved, the global systemic risks can in a first approach be grouped into two categories:

Trend risks They are linked to the long-term evolutions (several decades) of our globalized socio-ecosystem. They are essentially due to the growing tension between our use of resources, our production of varied and often diffuse pollution, and the capacity of our (semi-)natural environment to absorb the associated impacts, as well as to the consequences of the induced environmental changes on the said socio-ecosystem. These risks are both amplified and underpinned by specific socio-political, economic and historical dynamics.

Risks of Systemic Contagion These are shorter term (weeks or months) but intermittent and random. This type of risk is linked to the very high level of global interconnections between numerous sectors of human activity, to the intrinsic instabilities generated by these interconnections, and to their possible propagation by domino effects in all sectors of society. These risks are intensified by the current geopolitical dynamics, and by the aggravation of environmental problems.

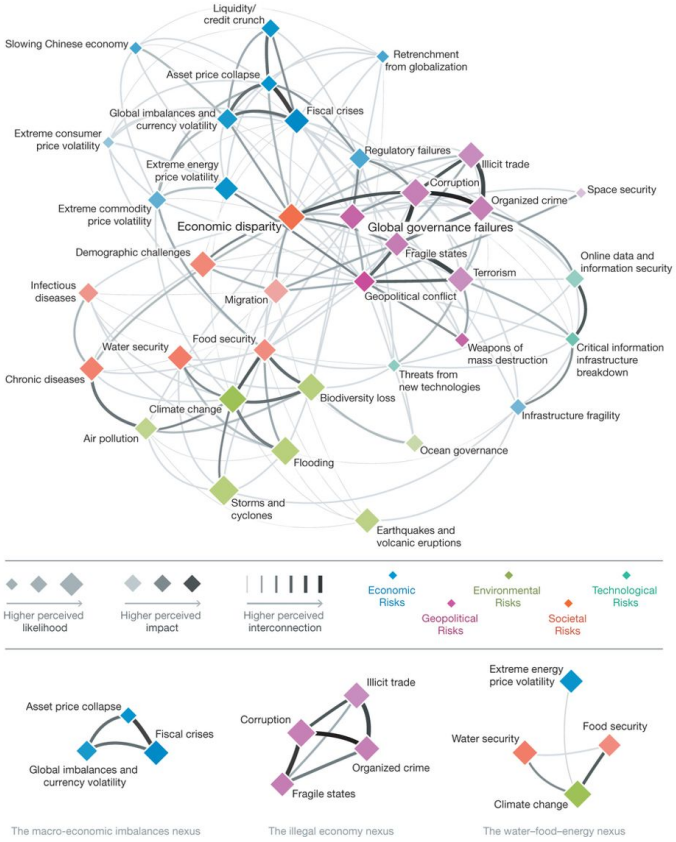

Figure 1: Global systemic risks and their interconnections according to the 2011 World Economic Forum report (reproduced in [41]). These risks are assessed by expert opinion and the importance attributed to them reflects in part cyclical concerns.

Project In this context, and because of its thematic and technical competences, the STEEP team is ideally positioned to make a significant contribution to this issue, both in terms of modeling and in terms of the interactions between modeling and historical, (geo)political and economic analyses. These two complementary angles should shed new light on these issues and on the associated strategic analyses.

Modeling in this kind of field, although intrinsically quantitative, cannot aspire to be quantitatively precise, but on the other hand can prove discriminating on a qualitative or even semi-quantitative level, the modeling exercise itself obliging to make explicit the presuppositions and expectations of the experts involved and of the modelers, and obliging in fact to be conceptually more precise and more coherent.

The present project aims on the one hand to study the validity and robustness of existing models of trend risks, and on the other hand to develop an innovative approach to modelling systemic contagion risks, a modelling which is only at an embryonic stage in the literature.

The emblematic model of the first category is the World3 model developed by the Meadows group for its famous report on the limits to growth [46, 45]. The re-analyses of [48, 49] and [35] have renewed interest in this model while raising more specific questions about the robustness of the conclusions drawn from it. We plan to answer these questions through an analysis on three complementary fronts:

1. An analysis of the choices of parameterization based on a sensitivity analysis that is much finer than the existing ones.

2. An analysis of modeling choices based on a sectoral and geographical disaggregation of the model.

3. Elements of epistemological analysis.

The main practical interest of this research lies in the possibility of discerning the risks of collapse in

the short term (pre-2050) or further out in time (post-2050), both of which require different mitigation and adaptation strategies that must be properly anticipated.

In terms of systemic contagion risks, and although an exhaustive analysis of all the categories of potential risks is impossible in an exploratory phase, the energy/finance/supply chain nexus plays a particular role in our societies and presents a specific criticality. Sectoral or cross-sectoral analyses of certain aspects of this nexus already exist in the literature (see for example [40, 43, 36]), but apparently no overall model has been produced on this subject, and in particular no dynamic model. Such a realization would constitute in itself a significant advance.

More precisely, the work envisaged concerns the following points:

1. Identify the most important feedback loops of the coupled energy/supply chain/logistics/finance system.
2. Identify the most fragile links in this system.
3. Assess the likelihood of this type of risk and, if necessary, define mitigation strategies.

3.2 Sociotechnical Alternatives

The Sociotechnical Alternatives research axis aims to study the material basis of the economy (in physical rather than in monetary units), to analyze its environmental impacts, and also to propose alternative economic structures in terms of modes of production and consumption. It is composed of two sub-axes: analyses of particular supply-chains (in the continuity of our previous works), and systemic analyses of sociotechnical alternatives for the economy as a whole, taking interactions between sectors into account.

In both cases, our aim is to produce multi-scale analyses (e.g.: local scale < French region < France < Europe < World) that will help to inform collective decision-making for a transition towards sustainable modes of production and consumption.

Supply chain analyses Material flows (production, transformation, exchanges, consumption, waste) are the basic building blocks of our supply chain studies. We designed methods and tools to model a supply chain (in terms of products, sectors and possible flows between them) and reconcile incomplete and/or inconsistent data. The flows allow:

- To apprehend up/downstream vulnerabilities of supply chains (e.g. dependence on imports),
- To question the use of natural resources and the possible problems of competition for use (e.g.: can the development of biofuels lead to competition between food and energy production?),
- And finally to estimate environmental footprints (e.g. carbon, energy, water, chemical pollution, land use, etc.).

So far, our research has mainly focused on the agriculture and forest-wood chains. Results and softwares are available on the following website (only in French for the time being): www.flux-biomasse.fr. A sample result is shown in figure 2. STEEP works closely with the TerriFlux company (startup of the team, created this year) on this topic.

Systemic analyses of sociotechnical alternatives The objective of this research program is to help shed light on the debates around possible alternatives: what would a one-planet economy look like and what standards of living would it imply? What compromises will have to be made between socio-economic and environmental criteria, between resilience, equity and sustainability of territories?

Our work is structured around four main objectives:

- To propose a formalism to describe sociotechnical alternatives. In particular, we are working on extensions of physical supply/use tables, able to provide information on the interactions between materials and energy. We are also interested in coupling quantitative (technical dimension) and qualitative (social dimension) representations.

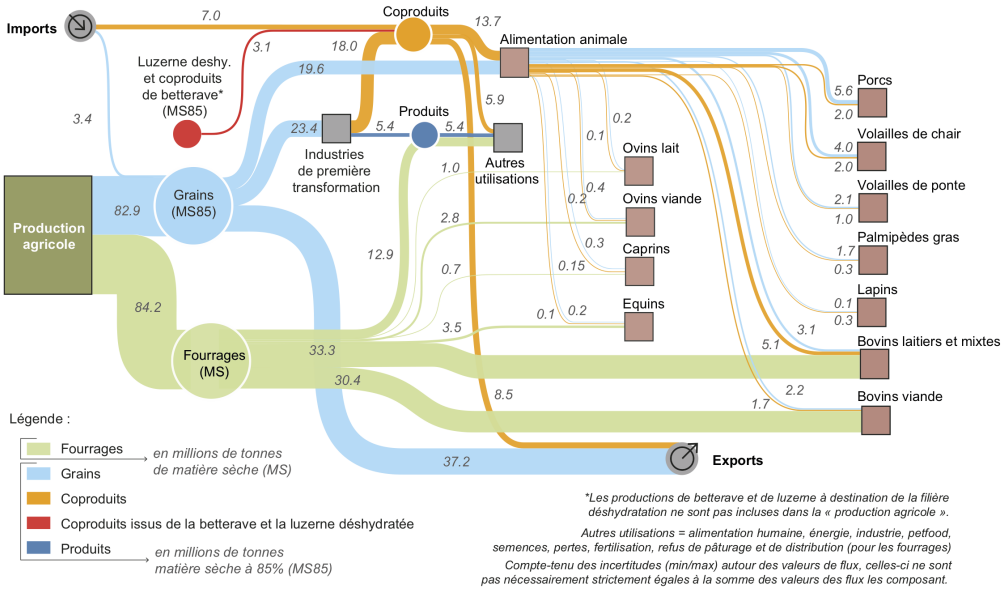

Figure 2: Sankey diagram of a supply chain (animal food production and supply).

- To propose a methodology (and eventually a software) allowing groups of actors to imagine their own alternatives,
- To develop a methodology and associated tools to evaluate an alternative (cf. figure 3):
  - What needs does it cover?
  - What are the local, remote or global pressures and impacts generated? How do they compare to local and global limits?
  - What would be the vulnerabilities of the system described?
  - What are the socio-economic performances of the system described (e.g., in terms of allocation of the workforce, allocation of added-value…)?
- To help comparing alternatives and structuring related debates.

4 Application domains

One of the characteristics and objectives of our research project is to try to provide integrated and systemic visions and approaches to reduce and prepare for the consequences (shocks, depletion of resources, etc.) due to the overshooting of planetary limits and to identify the room for maneuver and means of action available to us to act against them. It is an “applicative” project as such. Listing its fields of application does not really make sense. However, we can isolate parts of our activities that fit into specific scientific fields and communities. This is what we do here in a non-exhaustive way.

4.1 Ecological accounting for sectorial pressure assessment

One of the major issues in the assessment of the long-term sustainability of territories is related to the concept of “imported sustainability”. Cities in particular bring in from the outside most of their material and energy resources, and reject to the outside the waste produced by their activity. The modern era has seen a dramatic increase in both volume and variety of these material flows and consumption as well as in distance of origin and destination of these flows, usually accompanied by a spectacular increase in the associated environmental impacts. A realistic assessment of the sustainability of territories requires to

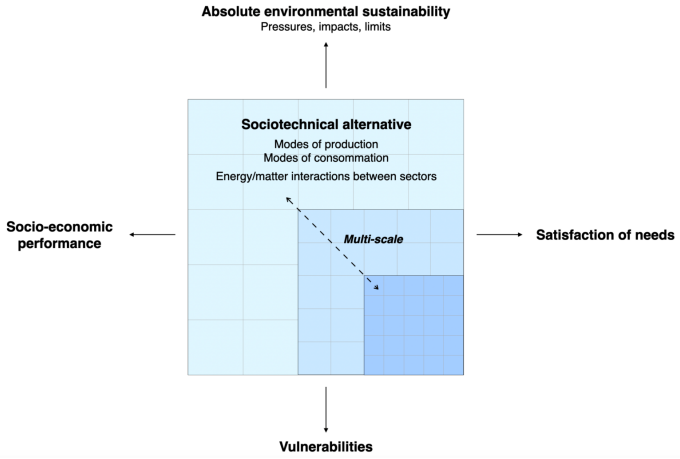

Figure 3: Schematic overview of research questions and concepts underlying sociotechnical alternatives. Center: targeted sociotechnical alternatives are typically of multi-scale nature. Borders: the four dimensions to be considered in evaluating sociotechnical alternatives (see text).

quantify both local and distant environmental impacts; greenhouse gas emissions are only one aspect of this question. Such an assessment brings to light the most relevant direct and indirect lines of action on these issues. In this respect, it is useful to introduce the alternative concepts of consumer versus producer responsibility (or point of view).

The producer point of view is the most useful to pinpoint relevant direct lines of actions on environmental pressures due to production. In other respects, any territory imports and exports goods and services from and to the rest of the world. The consumer point of view provides information on the indirect pressures associated with these exchanges, as production responds to a final demand. Tracking the various supply chains through the analysis of the structure of the local economy and its relations and dependencies to the external world allows us to identify critically important contributions to environmental pressures; this also enables us to define fair environmental indicators in order not to attribute environmental pressures to producers only (whose responsibility is the easier to quantify of the two). In this approach, the producer responsibility follows directly from the measurement of its energy and material uses, while the consumer responsibility is established indirectly through an allocation of the impacts of production to the final consumers, but this second mode of allocation is to some extent virtual and partly subjective.

STEEP is pursuing its research program on this theme with three major goals: 1) Creating a comprehensive database enabling pressure analyses; 2) Developing methodologies and models resolving scaling issues, and developing algorithms allowing us to rigorously and automatically obtain adequate assessments; 3) Providing a synthetic analysis of environmental pressures associated to the major material flows, at various geographic levels (employment catchment area, *département* and *région*, for France), with the explicit aim of incorporating this type of information in the public decision process on environmental issues, via specifically designed decision-help procedures.

4.2 Urban economy and land use/land cover changes: assessment of spatial distributions of the pressures

The preceding section was focused on territorial metabolism, in particular on the analysis of supply chains. Here territories are examined with a more prominent emphasis on their spatial dimension, with attention to: the spatial distribution of local pressures previously identified (from a land use point of view), and the modeling of future land use and activity location (from an economic point of view). These two questions correspond to very different modeling strategies: the first one is more statistical in nature, extrapolating future land use from past evolution combined with global territory scenarios; the other one has a more fundamental flavor and focuses on an understanding of the processes driving urbanization. For this, we focus more precisely on the question of household and businesses choices of localization, as

well as on spatial fluxes within the territory (transportation of goods and persons). The critical point here is to understand and manage urban sprawl and its environmental effects (GHG emission, loss of arable land, ecosystem fragmentation, and so on).

LUCC (Land Use/Land Cover Change) models are mostly used in environmental sciences, e.g. to evaluate the impact of climate change on agriculture, but they can also be used to analyze urban sprawl. There is a variety of models, static or dynamic, grid- or agent- based, local or global, etc., and with varying degrees of sophistication concerning spatio- temporal analysis or decision structures incorporated in the model.

The models of interest here are statistical in nature but spatially explicit. Following decades of development, they are robust, versatile and mature. In principle, agent-models have a larger potential for representing decision processes, but in practice this advantage results in a loss of universality of the models. Among the most well-known and most mature models, one can mention the CLUE family of models, DINAMIC, or LCM (Land Change Modeler). These models are well described in the literature, and will only be briefly presented here.

These models analyze change in land use in a statistical way; they are structured around three different modules:

- The first module determines the probability of change of pixels of the territory (pixels are typically tens to hundreds of meters in size).
- The second module defines the global changes between the various land uses of interest per time step (usually, a few years), based on global scenarios of evolution of the territory under study. These first two modules are independent of one another.
- The last module distributes changes of land use in an explicit manner, pixel per pixel, at each time step, on the basis of the information provided by the first two modules.

Probabilities of change are calibrated on past evolution, from the differences between two past maps of land use in the more favorable cases, or from a single map otherwise (under the assumption that the logic of occupation changes is the same as the logic of land use at this single date). Such changes are then characterized in a statistical way with the help of modeling variables identified by the modeler as having potential explaining or structuring power (typically, a few to a dozen variables are used for one type of land use change). For example, in the case of urban sprawl, typical explaining factors are the distance to existing urbanized zones or distances to roads and other means of transportation, elements of real estate costs, etc. Global scenarios are quantified in terms of global changes in land use over the whole studied area (e.g., how many hectares are transformed from agricultural to urban uses in a given number of years, how does this evolve over time...); this is done either from academic expert knowledge, or from information provided by local planning agencies. Whenever feasible, models are validated by comparing the model predictions with actual evolution at a later date. Therefore, such models need from one to three land use maps at different dates for calibration and validation purposes (the larger the number of maps, the more robust and accurate the model). A large array of statistical tools is available in the literature to perform the calibration and validation of the model.

The horizon of projections of such models is limited in time, typically 20-30 years, due to the inherent uncertainty in such models, although they are occasionally used on longer time-scales. Climate change constraints are included, when needed, through scenarios, as it is not in the scope of such models to incorporate ecological processes that may translate climate change constraints into land cover change dynamics. Note that on such short time-scales, climate change is not dominated by the mean climate evolution but by decade variations which average out on longer time-scales and are not modeled in the global climate models used e.g. for IPCC (Intergovernmental Panel on Climate Change) projections for the end of the century; as a consequence, the various IPCC climate scenarios cannot be distinguished on such a short time horizon.

With regard to LUCC, the STEEP team has been involved for five years in the ESNET project whose funding came to a close in July of 2017, but the scientific production of the project is still underway. This project bears on the characterization of local Ecosystem Services networks; the project has been coordinated by LECA (Laboratoire d'Ecologie Alpine), in collaboration with a number of other research laboratories (most notably, IRSTEA Grenoble, besides our team), and in close interaction with a panel

of local stakeholders; the scale of interest is typically a landscape (in the ecologic/geographic sense, i.e., a zone a few kilometers to a few tens of kilometers wide). The project aims at developing a generic modelling framework of ecosystem services, and studying their behavior under various scenarios of coupled urban/environment evolution, at the 2030/2040 horizon, under constraints of climate change. The contribution of the STEEP team is centered on the LUCC model that is one of the major building blocks of the whole project modelling effort, with the help of an ESNET funded post-doctoral researcher. In the process, areas of conceptual and methodological improvements of statistical LUCC models have been identified; implementing these improvements will be useful for the LUCC community at large, independently of the ESNET project needs.

4.3 Territorial foresight studies

The direct application of research axis Sociotechnical Alternatives (see previous section) lies in foresight studies for territories. Tools and methodologies we are developing are aimed at decision-aiding. One aspect is to help stakeholders to structure their foresight exercises, for instance by asking them to explicitly express their objectives and allowing them to design sociotechnical alternatives. Another aspect is to provide tools and concepts for assessing these alternatives, according to different dimensions. An overarching issue is the embedding of these tools and activities in participative processes.

5 Social and environmental responsibility

5.1 Footprint of research activities

While the team does not apply any strict formal rules concerning the following issues, it is probably safe to say that a certain level of awareness on environmental issues that is natural given our line of work, guides many of our "daily" decisions. Examples of how environmental impacts are considered are provided in the following.

Contrary to what some might suspect, we do use computers, networks and other digitial equipment for our research... meaning that the direct footprint of our research activities is higher than if we were working with pen and paper only... Generally speaking, we aim at keeping our footprint as low as possible given the requirements of our work. For instance, computing equipment is used as long as possible (the current average age of our desktop computers for instance, is more than 8 years and these lines are written on a notebook of 9 years of age). Criteria for choosing publication venues include where conferences are held (to lower the footprint of work travel). The number of trips by plane in the last years is probably below the Inria average. Many team members use the bicycle for home-to-work trips, sometimes for work trips as such. The ratio of vegetarian over meat-based dishes taken for lunch at the local cantine, is rather high compared to the national average. The majority of our collaborations, be they with academic or with other partners, are local (in Grenoble or within the Région). This is natural given that our work requires partnerships with territorial authorities for instance, but is also a matter of choice. Besides trying to limit the direct footprint of our work, some team members are also involved in initiatives whose general aim is to reduce the environmental impact of research, such as Campus1point5Grenoble and MakeSEns.

Having said all this, we think that on average, the environmental and social impact scientists have is dominated by the topics and applications they choose to work on, more so than by the direct impact of their day-to-day work-related activities.

5.2 Impact of research results

All of the team's research activities are directly dedicated to environmental and social issues. On the one hand, this concerns both of our research axes – Global Systemic Risks and Sociotechnical Alternatives – and on the other, the type of collaborations we build to underpin these axes – partnerships with different territorial and environmental bodies and also more and more with civil society.

Besides research activites *per se*, we also pursue various dissemination activities related to social and environmental issues, towards general audiences, and give transdisciplinary university courses.

6 Highlights of the year

Terriflux is a consultancy founded in 2021 after one year of incubation in Inria Startup Studio. It aims at valorizing the methods and tools for material flow analysis developed in the STEEP team. The expertise is focused on two pillars: a software for material flows analysis in supply chains based on data reconciliation and a software for data visualization and exploration in the form of interactive Sankey diagrams. These tools have already been implemented on a large number of sectors (agricultural and forestry) and geographical scales (France, French regions, departments), whether in the context of research projects or commercial services; see some examples. Julien Alapetite is the founder and manager of Terriflux. He is a computer developer and a geostatistical engineer by training. He is a long time member respectively collaborator of the STEEP team and co-developed the softwares.

The analysis of the energy return (EROI) of oil and gas performed in [15, 16] indicate that the energy cost of fossil liquids and gases extraction is on the brink of a severe increase. In particular, by 2050, half the extracted oil will be used for oil production itself, reducing by as much the oil available for other economic and social uses, in a context where increasing oil production will become more and more difficult, for geological and economic reasons. This may challenge the advocated shift to renewable energies or other forms (nuclear, e.g.) of energies as a result of rising economic tensions, difficulties associated with a massive electrification of energy uses, and potential increases in the energy cost of material extraction (in particular for copper, a structural metal of vital importance for the energy transition). Even if these difficulties in fossil liquid production imply that the most severe climate change IPCC scenarios will probably be avoided, we may still be confronted to a slow energy transition resulting in our inability to maintain global warming below 2°C (or even 3°C) by the end of the century. This is why a thesis on the feasability of the energy transition (Antonin Berthe) has been started in the STEEP group, in collaboration with Olivier Vidal from ISTerre (Grenoble University), a well-known expert on energy/material coupled analyses.

This year was the first time since its creation that the team could recruit a permanent member through a *concours* (Jean-Yves Courtonne, Inria SFP). The other permanent members had created/joined the team through thematic mobilities, after having been recruited in other disciplines/labs.

7 New results

7.1 Peak oil and the low-carbon energy transition: A net-energy perspective

Participants: Louis Delannoy, Pierre-Yves Longaretti, Emmanuel Prados, David J. Murphy (St Lawrence University).

Since the Pennsylvania oil rush of 1859, petroleum has quickly become the dominant fuel of industrial society.The “Peak Oil” debate focused on whether or not there was an impending production crunch of cheap oil, and whilst there have been no shortages across the globe, a shift from conventional to unconventional oil liquids has occurred. One aspect of this shift was not fully explored in previous discussions–although of some importance in a low-carbon energy transition context: the extent to which the net-energy supply of oil products is affected by the use of lower quality energy sources. To fill this gap, this paper incorporates standard EROI (energy-return-on-investment) estimates and dynamic decline functions in the GlobalShift all-liquids bottom-up model on a global scale. We determine the energy necessary for the production of oil liquids (including direct and indirect energy costs) to represent today 15.5% of the energy production of oil liquids, and growing at an exponential rate: by 2050, a proportion equivalent to half of the gross energy output will be engulfed in its own production. Our findings thus question the feasibility of a global and fast low-carbon energy transition. We therefore suggest an urgent return of the peak oil debate, but including net-energy issues and avoiding a narrow focus on ‘peak supply’ vs ‘peak demand’. This work has been published in [16]. An analogous study on natural gas has been published in [15].

7.2 Analysing the validity and robustness of the iconic World3 global model

Participants: Mathilde Jochaud Du Plessix, Serge Fenet, Pierre-Yves Longaretti.

World3 [47, 45] is a flagship complex model. It was the first to widely explore potential future global socio-environmental trends, and to point out in a focused and sophisticated manner the possible dire consequences of forced growth in a finite and constrained environment. Since the inception of its first version in 1971, it has attracted a lot of attention, comments, praises and criticisms. Many were however based on shallow arguments, and of the few in-depth analysis of the model that have been performed, most were carried out in an early period and lead to some incorrect conclusions due to their highly generic level of assessment of the model input parameters. The interest in the model has been revived in the last decade or so, in light of the growing concerns about planetary limits and the impact of human activity on natural systems, and following a widely-circulated ex post analysis made in 2014 [49]. Along with the availability of recent data, this revival of interest fueled the need to re-evaluate both the robustness of the model and the validity of its conclusions. This task presents, however, a delicate epistemological dimension: how can we evaluate the validity of a model with only one historical instantiation, and whose focal point of projection lies in the future? Our work focuses on the first two steps in the answer to this question. First, we have performed an extensive analysis of the parameterization choices made by the authors of the model, based on a comprehensive sensitivity analysis made possible by modern computing power. This analysis relies on a one-step-at-a-time screening method and a variance decomposition method. It allowed us to identify the most influential parameters in an objective way. Second, after having developped a coarse-grain analysis of the dynamics of the main variables of interest, we performed an fine-grain analysis of the inner dynamics of the model based on the relative importance of its feedback loops, and whose computational complexity was reduced by a decomposition in minimal independent loop sets [24]. As the relevance of the model gathers a new importance in the emerging Anthropocene era, the result of this work is the first comprehensive loop structural dominance analysis of the World3 model, letting us objectively describe the temporal dynamics of the feedback loops linking the variables of interests.

7.3 Scenarization of sociotechnical alternatives

Participants: Olivier Mauviel, Jean-Yves Courtonne, Guillaume Mandil, Peter Sturm.

Material flow analysis can be used to model existing sociotechnical systems. However, this framework can also be used to model and study sociotechnical alternatives for the future of a territory (cf. section 3.2). We plan to approach the modeling of sociotechnical alternatives through modules. A module may be seen as an aggregated subpart of an economy, that receives certain flows as input and produces output flows. It is important to choose an adequate level of aggregation, useful for the construction of sociotechnical alternatives: this concerns both, the perimeter of the production, transformation and consumption processes that are embodied in a module, and the parameters steering these processes. As for the latter, the idea is to split them into two sets, one that remains hidden inside the module (such as technical coefficients) and the other that is made accessible to the user. Intuitively, these steering parameters shall enable the user to conceive meaningful and contrasting sociotechnical alternatives; they may relate to the distribution among main agricultural production modes or to food regime choices. In [25], a first description of this approach is provided. Ongoing and future work addresses several issues. First, formulating and solving the so-called reconciliation problem that arises when combining several modules to represent a sociotechnical alternative: how to compute, from user-set steering parameters, reconciled parameter values that lead to input/output flows that are completely consistent across modules. Second, methods that enable users to construct a sociotechnical alternative in a step-by-step manner; this requires for instance tools to guide the user such as to avoid inconsistent scenarios. Third, to “implement” actual modules and to build actual sociotechnical alternatives: first for research purposes, helping the development of our tools, but increasingly as part of participative exercises with actual users in territories.

7.4 Multi-unit data reconciliation for input-output tables in physical flows

Participants: Alexandre Borthomieu, Jean-Yves Courtonne, Guillaume Mandil, Peter Sturm, Vincent Jost (G-SCOP Laboratory, Univ Grenoble Alpes).

There are now several research works dealing with input-output tables in physical flows. These works are crucial to try to answer questions about the possible trajectories of our societies and consumption patterns. In [19], we bridge this work with material flow analysis and develop a methodology able to provide physical flow tables in a common formalism from data expressed in several physical units. An example is energy production: an energy production facility transforms an input material flow represented as a mass, into an energy flow (expressed in GWh for instance) as well as waste materials (mass). A coherent description of such processes from measured data that may be incomplete and/or uncertain, requires the solution of a particular data reconciliation problem. In [19] we provide several solutions for this. Such multi-unit reconciliation problems arise in particular when merging multiple material flow analyses, in order to establish a complete description of an entire economy. In the upcoming year we plan to establish an integrated material flow analysis for the French economy.

7.5 A Formally Correct and Algorithmically Efficient LUCL change Model-Building Environment

Participants: François-Rémi Mazy, Pierre-Yves Longaretti.

The use of spatially explicit land use and land cover (LULC) change models is widespread in environmental sciences and of interest in public decision-help. However, it appears that these models suffer from significant biases and shortcomings, the sources of which can be mathematical, conceptual or algorithmic. We formalize a modeling environment that distinguishes a calibration-estimation module and an allocation module. We propose an accurate calibration-estimation method based on averaged shifted histograms and detail an unbiased allocation algorithm. Moreover, a method of evaluation of LULC change models is presented and allows us to compare them on various fronts (accuracy, biases, computational efficiency). A case study based on a real land use map but with known (enforced) transition probabilities is used. It appears that the error of the methods we propose is four times smaller than than of the best existing software, and considerably more accurate than most software. Moreover, these methods make use of only a very limited number of user-specified parameters and are numerically extremely efficient (up to a factor of 100 faster than existing software). This work has been accepted for publication in 2022.

7.6 What are the right scales for the (re)localization of production systems

Participants: Léon Fauste, Jean-Yves Courtonne, Guillaume Mandil.

Léon Fauste's internship (April to August 2021) [32] was an opportunity to open a new line of questioning around the relevant geographical scales for organizing and/or relocating production systems. This internship allowed to show some possibilities to combine several approaches from the literature [39, 44] with the tools and methods of multiscale analysis of production chains already developed in the STEEP team. Léon will continue this work in his thesis by actually developing one or more of the possibilities highlighted during the internship [23].

7.7 Analysis of material flows in the animal supply chains

Participants: Maxime Latgé, Julien Alapetite, Jean-Yves Courtonne.

Maxime Latgé, an engineer student at the Ecole des Mines de Nancy, did his internship in the STEEP team [34]. He worked for the SCALABLE project on the analysis of material flows in the animal supply chains (in particular, cattle, porc, poultry meat) at the scale of France and of the 13 French regions. His results will serve as a basis for several works in 2022.

7.8 Influence of power relations on the circularity of waste flows at the territorial scale: Analysis of the building sector in Grenoble Alpes Métropole

Participants: Quentin Desvaux, Jean-Yves Courtonne, Guillaume Mandil, Catherine Figuière (CREG lab, Univ Grenoble Alpes).

This work is done in the framework of Qentin Desvaux's CIFRE PhD thesis in collaboration with the STEEP team, the CREG lab, and Grenoble Alpes Métropole.

Grenoble Alpes Métropole has initiated an ambitious approach aimed at reappropriating waste deposits by transforming local production systems in an attempt to address the convergence of territorial issues of governance and industrial change with global issues of resource scarcity and pollution. This research work in political economy allows for an open disciplinary approach [38] in order to analyze the metropolis' waste management channels from two complementary approaches: (i) a functionalist approach that brings to light the interdependent relationships between society and its environment through the analysis of flows; and (ii) a relational approach to integrate neo-Marxist interpretations of flow structuring and account for the historical and social processes responsible for power asymmetries [42].

7.9 Designing sociotechnical organizations through the biophysical description of territorialized supply chains

Participants: Emmanuel Krieger, Jean-Yves Courtonne, Mathieu Mangeot.

Humans are having more and more impacts on environment due to unsustainable consumption and production patterns, thus threatening the capacity of natural systems to support their long-term existence. To help reaching a desirable and sustainable societal organisation, it is notably helpful to estimate the desirability of possible alternatives to the current sociotechnical organisation. To move forward in this direction, we aim at designing a systemic modelling tool which could enable actors to design their own projection of a sociotechnical alternative, and to evaluate it with multi-criteria indicators. The foundations for the realisation of the model are built upon the biophysical description of territorialized supply chains. The Supply Chain – Material Flow Analysis formalism is chosen to describe biophysical economy through the establishment of six material based French national supply-chains which are non-metallic minerals, fossil fuels, metals, waste, water and energy supply chains. Furthermore, we built a first prototype based on the establishment of the material flows of urban mobility [30]. This tool can be used to design urban transport alternatives as well as to proceed to an environmental assessment of these alternatives. The next steps are the creation of a multi-supply chain and multi-scale systemic model.

7.10 Participatory research on the use and impact of material flow models for foresight in the face of transition issues in territories

Participants: Mathilde Boissier, Emmanuel Krieger, Jean-Yves Courtonne, Guillaume Mandil, Mathieu Mangeot, Peter Sturm, Nils Ferrand (INRAE, G-Eau lab, Montpellier).

As described in section 4.3, we intend to enable the development of sociotechnical alternatives for territories within participative processes. The objective is to develop participative processes allowing the actors of the territory to transform it, and in which systemic models such as material and energy flows would help in the exploration and dialogue on vulnerabilities and in the construction of coherent sociotechnical alternatives. While we are still developing tools (methodologies, approaches, software) to construct and assess sociotechnical alternatives, as explained in the previous sections, we have already started this year work towards participative processes. The first activity is a project with students from Université Grenoble Alpes that aims at devising a serious game targeted at territorial actors and whose aim is to raise awareness on environmental issues and in particular, on systemic links between natural and human processes. Next steps will be for instance:

- Establishment of a multidisciplinary interface between biophysical systemic models such as material and energy flows, participatory processes and in particular participatory modeling and simulation and prospective approaches.
- Development of a participatory methodology using the paradigms of the matter and energy flow analysis models.
- With a longer time scale, implementation of the methodology on a real territory (discussions with several municipalities have been initiated).

8 Partnerships and cooperations

8.1 National initiatives

8.1.1 SCALABLE – Metabolism of agricultural biomass: multi-scale representations, vulnerability analysis and evaluation by local stakeholders

Participants: Jean-Yves Courtonne, Maxime Latgé, Guillaume Mandil.

Project funded by ADEME
Duration: 2021-2024 (36 months)
Coordinator: Sophie Madelrieux (Inrae Grenoble), Jean-Yves Courtonne for Inria partner.
Partners: LESSEM (Inrae Grenoble), Auvergne-Rhône-Alpes Énergie Environnement, TerriFlux, Parc Naturel Régional de Chartreuse, STEEP (Inria Grenoble).
Keywords: agriculture value chains, multi-scale analysis, multicriteria analysis, vulnerabilities, participative evaluation.
Abstract: SCALABLE focuses on agricultural biomass, on the different transformation steps (supply chain) from production to consumption, at several geographical scales (national, regional, local). The projects aims at improving knowledge on material and organizational vulnerabilities of territories with respect to these supply chains: to what extent are the needs of the local population satisfied in a sustainable way, and without transferring vulnerabilities to other territories? This work will be conducted by coupling an analytical approach (use of descriptive models) with a deliberative approach (evaluation by local stakeholders). It will also lay a basis for assessing the relevant scales of relocation of the different sectors of the value chains.

8.1.2 TRAJECLIM – Resilience of a polar socio-ecosystem facing anthropic and climate change

Participants: Serge Fenet.

Project funded by CNRS
Duration: 2021-2023 (14 months)
Coordinator: Roman Teisserenc (Laboratoire Ecologie Fonctionnelle et Environnement, UMR5245), Serge Fenet for Inria partner.
Partners: UMR5503 (INP, Toulouse), UMR5245 (Université Paul Sabatier, Toulouse), UMR8212 (Gif-sur-Yvette), EA3816 (FoReLLIS, Poitiers), EA827 (Laboratoire d'Études et de Recherches Appliquées en Sciences Sociales, Toulouse), STEEP (Inria Grenoble).
Keywords: island model, systemic approach, résilience, systemic levers, storytelling.
Abstract: As a polar city of 5000 inhabitants created ex-nihilo in 1929, Igarka is a small urban island in the middle of Siberia that suffers from climate change, social decline (-75% of inhabitants), and industrial decline (linked to the cessation of forest exploitation at the end of the 20th century). However, the accounts of the inhabitants talk about both optimism and resilience in the face of these global trajectory bifurcations, mainly forced by the climatic repercussions of human activities, and by political context. Thus, in a sense, Igarka can be considered as a herald for our own territories and societies confronted to the current global changes. Preparing a Horizon Europe project, TRAJECLIM project wants to initiate an interdisciplinary analysis of Igarka's trajectory and its observed resilience, using multiple systemic approaches. It will rely on the study of the biogeochemical carbon and contaminants cycles, as well as indigenous, historical, literary and artistic narratives from the city inhabitants. It will produce a meta-analysis of the dynamics and bifurcation points the city had to deal with, as well as an inventory of the levers and tools of resilience invented by the population in the face of climate change.

8.2 Regional initiatives

8.2.1 QAMECS / MOBIL'AIR: ATMOSPHERIC POLLUTION: Characterization of novel exposure markers, of biological, health, economic and societal impacts and evaluation of public policies

Participants: Emmanuel Prados, Peter Sturm.

Project funded by ADEME, Grenoble metropolis, IDEX Universite' Grenoble Alpes
Duration: 2016–2021
Project coordinator: Rémy Slama (INSERM) and Sandrine Mathy (GAEL, CNRS). Inria Coordinator: Emmanuel Prados
Other partners: Air Rhône-Alpes, CNRS, Sciences Po Grenoble, Inserm, IAB, Université Grenoble-Alpes.
Abstract: Urban atmospheric pollution is one of the main threats to human health that can be to some extent controlled by public action. In Europe, many cities have implemented various types of low emission zones (LEZ, focused on traffic and heating emissions), France being a notable exception. Although fine particulate matter (PM2.5) is usually assessed through its mass concentration, other metrics, such as PM chemical speciation as well as the so far little considered oxidative potential (OP) of PM, are worth considering, both in terms of associations with human health and in the context of monitoring of the efficiency of LEZ. QAMECS covers all dimensions from atmospheric emissions, impact of meteorological conditions on air pollution human behaviours related to transportation, environmental levels, health, associated economic costs and societal awareness. The project relies on environmental measurements, modelling, repeated observational (representative) population studies, an existing mother-child cohort, a controlled human experiment, health impact and related economic assessment. It is conducted by a consortium of specialists of chemistry and physics of air pollution, economics, sociology, epidemiology, geography, in relation with local authorities. It will bring results important for urban planning, public health, and more fundamental research on the measurement of PM and assessment of their biological and health impact.

9 Dissemination

9.1 Promoting scientific activities

Participants: Mathilde Boissier, Jean-Yves Courtonne, Louis Delannoy, Denis Dupré, Serge Frenet, Pierre-Yves Longaretti, Matthieu Mangeot, Guillaume Mandil, Régis Perrier, Emmanuel Prados, Peter Sturm.

9.1.1 Archipel 2022 Conference

We organize the Archipel 2022 conference[2] on "Global systemic risks, trajectories and transdisciplinary levers for action". It is a french-speaking conference that aims at building a transdisciplinary scientific collective in order to formalize important questions, salient points, frameworks of thinking, methods and tools for dealing with the current global systemic issues, and more globally with the future of our societies.

The goals of this conference are to:

- bring together a community of scientists originating from diverse backgrounds, and adopting shared systemic approaches to global issues;
- co-construct and consolidate frameworks of thinking, knowledge and methodologies on global systemic risks, their assessment and mitigation;
- make concrete progress in the production and dissemination of scientific knowledge regarding global systemic risks.

The steering committee is composed by Mathilde Boissier, Louis Delannoy, Denis Dupré, Serge Fenet, Mathieu Mangeot and Emmanuel Prados, but the whole STEEP team is involved in the organization of the event.

The whole structure of the conference is taylored to promote scientific interaction. For example, the accepted submissions will be presented in a collaborative way, in symposiums that will be organized around core issues that will be addressed from different points of views to promote discussions. Several worshops will be organized in order to foster dedicated spaces in which the civil society will be able to directly interact with scientists.

This is the first instance of the conference, and more than 60 submissions have been received.

9.1.2 Global Systemic Risks seminar

From September 2 to 4, 2021 was held a seminar on **Global Systemic Risks**, jointly organized by the Mineralogy team of the ISTerre laboratory, the STEEP research team of Inria Grenoble and the Environmental Justice Program of Georgetown University. The seminar brought together political and scientific actors, who use different approaches to understand, model and anticipate systemic risks, their causes and consequences. The objective of this seminar was to meet and develop a common language, to present the systemic risk models currently under development, to assess potential collaborations and to raise the interest of political actors. As a result of the numerous interactions and the collective enthusiasm, a next seminar is already planned for June 2022.

9.1.3 Workshop on social security for food

In parallel to Bernard Friot's conference in our "Understanding and acting" series (see section 9.4), the STEEP team organized a workshop on the concept of a social security for food (SSA, sécurité sociale de l'alimentation) at the end of November 2021. This workshop aimed to bring together scientists, members of civil society (associations, unions, producers' cooperatives) and elected officials, with the objective of setting up a collective dynamic of reflection on the avenues to be explored in order to bring about a social security for food in the Grenoble metropolis. A second meeting is planned for February 2022.

[2] The initial name for the conference, appearing in the 2020 activity report, was Oasis.

9.1.4 Scientific events: selection

Member of the conference program committees

- Peter Sturm was a member of the programme committee of ORASIS 2021 (Journées jeunes chercheurs en vision par ordinateur)

9.1.5 Journal

Member of the editorial boards

- Since September 2020, Guillaume Mandil is editorial manager of the web site of "L'encyclopédie de l'energie".

- Participation of Emmanuel Prados in the editing and writing of the Inria–INRAE white book entitled "Agriculture et Numérique – Tirer le meilleur du numérique pour contribuer à la transition vers des agricultures et des systèmes alimentaires durables" (Agriculture and Digital – Getting the best out of digital to contribute to the transition towards sustainable agriculture and food systems), initially as an editor, then later only as a contributor (this change of status was motivated by personal ethical reasons and was done at the request of Emmanuel Prados himself).

Reviewer - reviewing activities

- Jean-Yves Courtonne reviewed papers submitted to *Ecological Economics*

9.1.6 Invited talks

- Emmanuel Prados gave an Invited Lecture at the *Congrès des Jeunes Chercheurs et Chercheurs en Mathématiques Appliquées* - CJC-MA 2021 on 28 October 2021, in Palaiseau, Île-de-France (École polytechnique campus). Plenary conference entitled "Mathematics, technologies and the environment: What responsibilities, what meaning and what positions to adopt in the face of environmental and societal catastrophe?"

9.1.7 Scientific expertise

- Guillaume Mandil is member of the scientific committe of the "Parc Naturel Régional de Chartreuse" since September 2020.

- Guillaume Mandil is member of the "comité opérationnel" of the Grenoble Metropolitan area citizens' convention for the climate

- Emmanuel Prados is a member of the scientific committee of the city of Grenoble. This committee is involved in the preparation of the events for "Grenoble 2022 Europeen Green Capital".

- Jean-Yves Courtonne is a member of the Steering Committee (COPIL) of the Territory consortium.

- Pierre-Yves Longaretti and Mathieu Mangeot are members of the scientific council of the *IDÉE* association that is dedicated to the innovation and development in environmental economics and that gathers industrial actors in the greater Annecy area.

- Strategic events and position paper on "Decarbonated energy, climate change, environmental health and biodiversity: impacts of our choices on the new interdisciplinary research directions", organized by the five French research alliances: Peter Sturm was one of the rapporteurs.

9.1.8 Research administration

- Emmanuel Prados and Guillaume Mandil are members of the "Campus D'après" initiative: a cross-disciplinary collective of academic researchers in the Grenoble area who share a common goal, to better understand and reduce the direct and indirect environmental impact of research.
- Peter Sturm is member (representative of personnel) of the CLHSCT of Inria Grenoble Rhône-Alpes (Local Committee for Hygiene, Security and Working Conditions).
- Peter Sturm is member of SEnS-GRA of Inria Grenoble Rhône-Alpes (commission on Science, Environnement and Society).

9.2 Teaching - Supervision - Juries

9.2.1 Teaching

- Emmanuel Prados, Pierre-Yves Longaretti, Guillaume Mandil along with Grégoire Chambaz and Anne Delaballe, launched the project **Anthropocene FACTS**. On the long run, the Anthropocene FACTS project aims to produce educational content on the trajectories of modern societies in the Anthropocene and to support the community of the contibutors and the users. The objective of this educational material is to present existing knowledge bearing on these trajectories in a critical manner in order to foster the development of critical skills and systemic global thinking. On the short run, in order to perform a first test of the approach and to serve as showcase of the whole project, the objective is to produce a small-scale prototype of such a pedagogical content under the form of a Spring School, which will take place from may 23rd to may 28th in Grenoble. To date, the scientific committee of the project is contituted of: Bert De Vries (University of Utrecht), Claude Mandil, Patrick Criqui (University Grenoble Alps), Stefan Giljum (Vienna University of Economics and Business), Sander Van Der Leeuw (Arizona State University).
- Jean-Yves Courtonne, Serge Fenet, Pierre-Yves Longaretti, Guillaume Mandil, Régis Perrier, Emmanuel Prados, and Peter Sturm: *Les véritables enjeux environnementaux – compréhension, modélisations et outils quantitatifs*, 24 hours, course plus project work, Master course, Ecole Centrale de Marseille.
- Jean-Yves Courtonne, Serge Fenet, Pierre-Yves Longaretti, Guillaume Mandil, Régis Perrier, Emmanuel Prados, and Peter Sturm: *Les véritables enjeux environnementaux – compréhension, modélisations et outils quantitatifs*, 24 hours course plus project work, MSTII Graduate School and L3 Computer science, UGA.
- Jean-Yves Courtonne, Guillaume Mandil: *Science, Environnement, Société*, Graduate School (CED) UGA.
- Emmanuel Prados gave a lecture at Polytech Nice Sophia on 10 December 2021 dealing with global systemic risks including societal and bio-geophysical collapse processes (5th year, Water Engineering speciality; 4h).
- Pierre-Yves Longaretti: *Changements globaux et risques globaux*, 6h, L1, UGA (PH208).
- Denis Dupré, Serge Fenet, Guillaume Mandil, Mathieu Mangeot and Régis Perrier have regular teaching duties at the universities employing them.

9.2.2 Supervision

- PhD defended this year: Michela Bevione, "Enjeux socio-écologiques, métabolisme territorial, création de richesse : application à la vallée de la Maurienne", supervised by Pierre-Yves Longaretti and Nicolas Buclet (PACTE laboratory).
- PhD in progress: Antonin Berthe, "Etude de la faisabilité de la transition énergétique. Modélisation des couplages énergie-matière.", supervised by Pierre-Yves Longaretti, Emmanuel Prados, Olivier Vidal (ISTerre).

- PhD in progress: Alexandre Borthomieu, "Méthodologie de description d'évaluation multicritère d'alternatives socio-techniques", supervised by Peter Sturm, Jean-Yves Courtonne, Vincent Jost (G-SCOP), Guillaume Mandil.
- PhD in progress: Louis Delannoy, "Global Systemic Risks: the Energy/Finance/Logistics/Agrofood Nexus", supervised by Pierre-Yves Longaretti and Emmanuel Prados.
- PhD in progress: Quentin Desvaux, "Re-conception de systèmes de production durables et territorialisés - apports croisés de l'écologie territoriale et de l'économie politique", supervised by Catherine Figuière (CREG), Guillaume Mandil, Jean-Yves Courtonne.
- PhD in progress: Léon Fauste, "Relocalisation d'industrie productive : une approche par les graphes et les contraintes", supervised by Christine Solnon (Lyon University) and Mathieu Mangeot.
- Phd in progress: Mathilde Jochaux du Plessix, "Analyse de la robustesse et de la validité des modèles dynamiques de risques systémiques globaux", supervised by Emmanuel Prados, Pierre-Yves Longaretti and Serge Fenet.
- PhD in progress: Olivier Mauviel, "Me'thodologie de conception d'alternatives socio-techniques", supervised by Peter Sturm, Jean-Yves Courtonne, Guillaume Mandil.
- PhD in progress: François-Rémi Mazy, "Theoretical Foundations of Land Use and Land Cover Change Modelling", supervised by Pierre-Yves Longaretti and Emmanuel Prados.

9.2.3 Juries

- Peter Sturm was a reviewer of the Habilitation thesis of Chaohui Wang (Université Paris-Est) and of the PhD theses of Toby Collins (Université Clermont Auvergne), Antoine André (Université Bourgogne Franche-Comté) and Jordan Caracotte (Université de Picardie Jules Verne), as well as a member of the PhD thesis committees of Mathieu Labussière (Université Clermont Auvergne) and Shiwei Li (Ecole Centrale de Lyon).
- Mathieu Mangeot is a member of the *Comité de Suivi Individuel* for tho PhD theses at Université Grenoble Alpes: Alexis Ladreyt and Rim Abouwarda.

9.3 Popularization

9.3.1 Articles and contents

- Jean-Yves Courtonne worked with the communication staff to present the team's research on biomass in Inria Grenoble communication booklet.

9.3.2 Education

- Peter Sturm and Emmanuel Prados gave a lecture on "Environmental challenges and what is blocking the action on them" during a week-long training course "Impact environnemental du numérique : comprendre et agir" organized by the EcoInfo network, Villard de Lans, France, June 2021.
- Peter Sturm, with Céline Serrano (DGD-A) and Sophie Quinton (SPADES), organized a quiz on the topic of sustainable development, for the members of the DGD-I (Direction for innovation of Inria) and the associated services.

9.3.3 Interventions

- Emmanuel Prados gave a conference to the elected officials of the city of Tencin on 28 January 2021 on "Global Systemic Risks" and on "institutional blockages slowing down or even preventing the ecological transition".

- Emmanuel Prados took part in the round table "Quelle est la place de l'ingénieur en informatique dans la transition environnementale ?" (What is the place of the computer engineer in the environmental transition?) of the Ethical and Sustainable Computer Science Day at Ensimag on Tuesday 9 November at the MaCI (Maison de la Création et de l'Innovation) on the UGA campus in Grenoble. Audience: 5th year engineering students of Ensimag.
- Emmanuel Prados gave four general audience conferences at Saint Laurent du Var and Saint-Jeannet in the Alpes-Maritimes department between 8 and 10 December 2021. Titles of the lectures: "Collapse announced of our civilization: causes, consequences and rooms for maneuver" and "Institutional and socio-political stakes in a world subjected to environmental constraints".
- Guillaume Mandil gave, on January 17, a talk on "Technology and sustainability" at the annual graduate seminar organized by SIF (French Society for Informatics).
- Guillaume Mandil made a presentation on "What role for (ICT) technologies in a sustainability perspective?" at the SICT graduate school.

9.4 Conference-debate series and YouTube-channel "Understanding and Acting"

Following a dynamics of exponential growth in a finite world, humanity today faces a number of unprecedented and tightly interlinked challenges. With a growing number of environmental limits being largely and irreversibly exceeded (GHG concentrations in the atmosphere, biodiversity loss, soil erosion, freshwater shortages...), social, economic, geopolitical, humanitarian (etc.) consequences are becoming more urgent than ever to address, while the threat of an uncontrolled global collapse is now more than a prospect. It is urgent to initiate deep, structural, socioeconomic changes on virtually all aspects of our increasingly global societies (economics, industrial and agricultural production, consumption, education, all requiring major new local and global policies).

In view of these facts, the STEEP research team has initiated in 2016 a series of conferences-debates entitled "Understanding & Acting" (*Comprendre et Agir*) that examines these issues in order to help researchers and citizens to increase their awareness of the various issues at stake in order to initiate relevant individual and collective actions. From now on, the scientific community at large must realize that its duty also lies in helping citizens to better understand these issues. If the fraction of people in society whose privilege is to be paid to think about society's problems do not seize this opportunity in the critical times we face, who will? Researchers must become more involved in the search of socioeconomic alternatives and help citizens to implement them. The interactions between researchers and citizens have also to be reinvented.

The presentations of this series of conferences typically last between 30 to 45 minutes; they are followed by a 45 minute public debate with the audience. The presentations are captured on video and then made directly accessible on the YouTube Channel "Comprendre et Agir". At the end of 2021 the YouTube channel has about 7,800 subscribers and reached a total of about 672,000 viewings.

The conference-debates of 2021 (for obvious reasons, several planned conference-debates had to be postponed, leading to a reduced program this year):

- Valérie D'Acremont (Unisanté, Université de Lausanne): *Technologies et santé : Quels compromis entre éthique, environnement et climat ? Analyse réflexive et expérience de terrain*, 27 September 2021.
- Bernard Friot (Université Paris Nanterre): *Responsabilité de la recherche dans le récit de notre histoire sociale ; exemple de la sécurité sociale*, 8 October 2021.

Links:

- Web site of the series ((program, abstracts, dates, complements etc.).
- YouTube channel

10 Scientific production

10.1 Major publications

[1] M. Bevione, N. Buclet, J.-Y. Courtonne and P.-Y. Longaretti. 'Socio-ecological transition, wealth creation and territorial metabolism: the case of the production of the AOC-labelled cheese Beaufort in the Maurienne Valley'. In: *ESEE 2019 - 13th International Conference of the European Society for Ecological Economics*. Turku, Finland, June 2019, pp. 1–4. URL: https://hal.inria.fr/hal-02430879.

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[7] L. Delannoy, P.-Y. Longaretti, D. Murphy and E. Prados. 'Peak oil and the low-carbon energy transition: A net-energy perspective'. In: *Applied Energy* 304 (Dec. 2021), pp. 1–17. DOI: 10.1016/j.apenergy.2021.117843. URL: https://hal.archives-ouvertes.fr/hal-03360253.

[8] L. Gervasoni, M. Bosch, S. Fenet and P. Sturm. 'A framework for evaluating urban land use mix from crowd-sourcing data'. In: *2nd International Workshop on Big Data for Sustainable Development*. Washington DC, United States: IEEE, Dec. 2016, pp. 2147–2156. DOI: 10.1109/BigData.2016.7840844. URL: https://hal.inria.fr/hal-01396792.

[9] J. Gippet, S. Fenet, A. Dumet, B. Kaufmann and C. Rocabert. 'MoRIS: Model of Routes of Invasive Spread. Human-mediated dispersal, road network and invasion parameters'. In: *5th International Conference on Ecology and Transportation: Integrating Transport Infrastructures with Living Landscapes*. Proceedings of the IENE 2016 conference. Lyon, France, Aug. 2016. URL: https://hal.inria.fr/hal-01412280.

[10] J. Lenglet, J.-Y. Courtonne and S. Caurla. 'Material flow analysis of the forest-wood supply chain: A consequential approach for log export policies in France'. In: *Journal of Cleaner Production* 165 (Aug. 2017), pp. 1296–1305. DOI: 10.1016/j.jclepro.2017.07.177. URL: https://hal.archives-ouvertes.fr/hal-01612454.

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10.2 Publications of the year

International journals

[14] M. Bevione, J.-Y. Courtonne, B. Nicolas, P.-Y. Longaretti and Q. Desvaux. 'Analyzing the vulnerabilities and capabilities of wealth creation activities in the Maurienne valley in the French Alps'. In: *Regional Environmental Change* (2022), pp. 1–44. URL: https://hal.archives-ouvertes.fr/hal-03560831.

[15] L. Delannoy, P.-Y. Longaretti, D. Murphy and E. Prados. 'Assessing Global Long-Term EROI of Gas: A Net-Energy Perspective on the Energy Transition'. In: *Energies* 14.16 (Aug. 2021), p. 5112. DOI: 10.3390/en14165112. URL: https://hal.archives-ouvertes.fr/hal-03322866.

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National journals

[17] P.-Y. Longaretti and F. Berthoud. 'Le numérique, espoir pour la transition écologique ?' In: *L'Économie politique* 90 (May 2021), pp. 8–22. URL: https://hal.archives-ouvertes.fr/hal-03233585.

International peer-reviewed conferences

[18] P. Sturm. 'Efficience : Quels Liens avec la Résilience et la « Sobriété » ?' In: ROADEF 2022 - 23ème congrès annuel de la Société Française de Recherche Opérationnelle et d'Aide à la Décision. Villeurbanne - Lyon, France, 23rd Feb. 2022, pp. 1–2. URL: https://hal.archives-ouvertes.fr/hal-03597201.

National peer-reviewed Conferences

[19] A. Borthomieu, J.-Y. Courtonne, V. Jost, G. Mandil and P. Sturm. 'Vers des tables en flux physiques de l'économie française'. In: S.mart 2021 - 17ème colloque national S-mart AIP-PRIMECA. Lille / Virtual, France, 31st Mar. 2021, pp. 1–10. URL: https://hal.inria.fr/hal-03180993.

[20] J.-Y. Courtonne, M. Boissier, A. Borthomieu, L. Fauste, V. Jost, E. Krieger, G. Mandil, M. Mangeot, O. Mauviel, C. Solnon and P. Sturm. 'Des outils numériques d'aide à la décision pour la conception et l'évaluation participative d'organisations alternatives de l'économie'. In: ROADEF 2022 - 23ème congrès annuel de la Société Française de Recherche Opérationnelle et d'Aide à la Décision. Villeurbanne - Lyon, France, 23rd Feb. 2022, pp. 1–2. URL: https://hal.archives-ouvertes.fr/hal-03595273.

Conferences without proceedings

[21] D. Dupré. 'Dialogue and radical imagination about property and survival'. In: 2021 - Conference on Environmental justice, Building back better "after Corona". Zoug, Switzerland, 29th Aug. 2021, pp. 1–146. URL: https://hal.archives-ouvertes.fr/hal-03279027.

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[23] L. Fauste. 'Support for the choice of geographic scale in the manufacturing industry through constrained optimization'. In: 23ème congrès annuel de la Société Française de Recherche Opérationnelle et d'Aide à la Décision. Lyon, France, 23rd Feb. 2022, pp. 1–2. URL: https://hal.archives-ouvertes.fr/hal-03560468.

[24] M. Jochaud Du Plessix, S. Fenet and P.-Y. Longaretti. 'Analysing the validity and robustness of the iconic World 3 global model: what can sensitivity and feedback loop analysis say?' In: CCS 2021 - Conference on Complex Systems. Lyon, France, 25th Oct. 2021, pp. 1–1. URL: https://hal.inria.fr/hal-03558243.

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Scientific book chapters

[26] V. Bellon Maurel, P. BONNET, I. Piot-Lepetit, L. Brossard, P. P. Labarthe, P. Maurel and J.-Y. Courtonne. 'Digital technology and agroecology: opportunities to explore, challenges to overcome'. In: *Agriculture and Digital Technology: Getting the most out of digital technology to contribute to the transition to sustainable agriculture and food systems*. White book INRIA 6. INRIA, 2022, pp. 76–97. URL: https://hal.inrae.fr/hal-03606035.

[27] B. Dedieu and E. Prados. 'Quels défis pour l'agriculture ?' In: *Agriculture et numérique : Tirer le meilleur du numérique pour contribuer à la transition vers des agricultures et des systèmes alimentaires durables*. Livre blanc INRIA 6. INRIA, 2022, pp. 22–31. URL: https://hal.inrae.fr/hal-03609391.

[28] F. Garcia, P. P. Labarthe, E. Prados, V. Bellon Maurel and G. Chambaz. 'Risques'. In: *Agriculture et numérique : Tirer le meilleur du numérique pour contribuer à la transition vers des agricultures et des systèmes alimentaires durables*. Livre blanc INRIA 6. INRIA, 2022, pp. 106–119. URL: https://hal.inrae.fr/hal-03609504.

Reports & preprints

[29] D. Dupré, J.-Y. Courtonne, S. Fenet and G. Mandil. *Le rôle particulier de la violence dans une « science des effondrements »*. 29th Oct. 2021. URL: https://hal.archives-ouvertes.fr/hal-03408890.

[30] E. Krieger, M. Mangeot, J.-Y. Courtonne, G. Mandil and P. Sturm. *A modelling tool for designing urban mobility alternatives and evaluating their direct and indirect environmental impacts*. 4th Jan. 2022. URL: https://hal.archives-ouvertes.fr/hal-03510573.

[31] G. Mandil, S. Allain, R. Bécot, E. M. Barbu, A. Bidaud, D. Dupré, C. Figuière, B. Hector, O. Gallot-Lavallée, S. Girard, J. Lolive, P.-Y. Longaretti, F. Maraninchi, G. Panthou, M. Rio, J. Riegel, C. Roncato Tounsi, C. Rossi and B. Tourancheau. *Anthropocène : Plan B, création de connaissances pour répondre aux enjeux sociétaux de manière soutenable dans les limites planétaires*. 11th Sept. 2021. URL: https://hal.inria.fr/hal-03341576.

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[33] E. Krieger. 'Describing and designing socio-technical organizations through the biophysical description of territorialized supply chains'. Mines de Paris, 25th Jan. 2022. URL: https://hal.inria.fr/hal-03562690.

[34] M. Latgé. 'Analyses de Flux de Matières de filières agricoles à l'échelle des régions françaises'. Mines Nancy, 28th Sept. 2021. URL: https://hal.inria.fr/hal-03551425.

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[49] G. Turner. *Is Global Collapse Imminent?, MSSI Research Paper No. 4. Melbourne Sustainable Society Institute, University of Melbourne*. MSSI Research Paper n° 4. Melbourne Sustainable Society Institute, University of Melbourne, 2014.