RESEARCH CENTRE

Grenoble - Rhône-Alpes

IN PARTNERSHIP WITH:

CNRS, Université de Grenoble Alpes

2020 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

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Project-Team STEEP

Creation of the Team: 2010 January 01, updated into 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

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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 [1]).

STEEP (Sustainability, Transition, Environment, Economy and local Policy) 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 [2] or to the Network

[1] https://www-ljk.imag.fr/index_en.php
[2] http://www.gmo-free-regions.org

of European Regions for a Competitive and Sustainable TouRism [3]). 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 [4]) 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.

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.

[3] http://www.necstour.eu

[4] 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.

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 [30] and [28]), or analysis from the social sciences (see for example [25]). 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.

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.

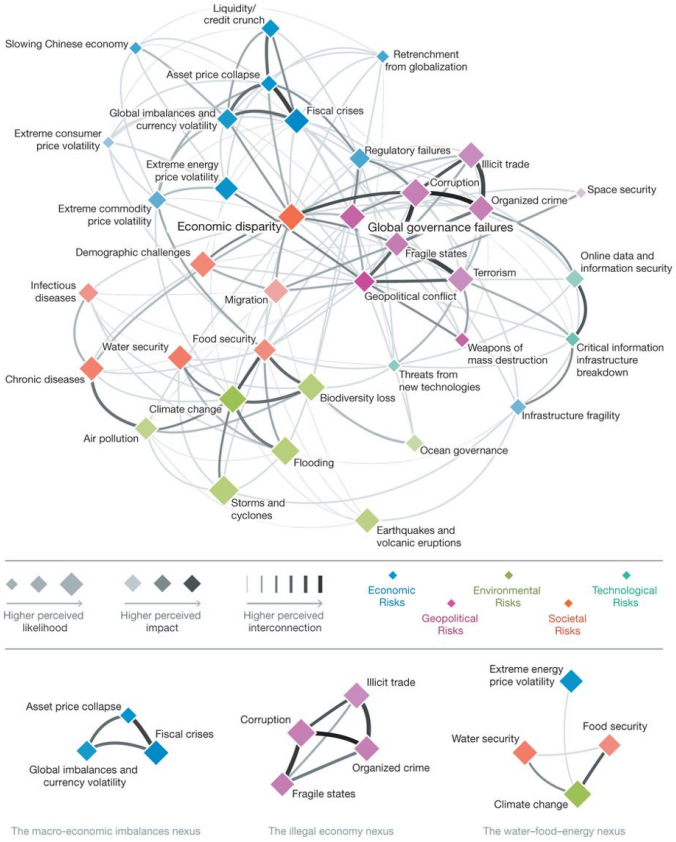

Figure 1: Global systemic risks and their interconnections according to the 2011 World Economic Forum report (reproduced in [28]). These risks are assessed by expert opinion and the importance attributed to them reflects in part cyclical concerns.

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 [31, 30]. The re-analyses of [35, 36] and [21] 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 [27, 29, 24]), 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): `http://www.flux-biomasse.fr`. A sample result is shown in figure 2. STEEP works closely with the TerriFlux company (startup of the team, currently in incubation phase) 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.
- 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?

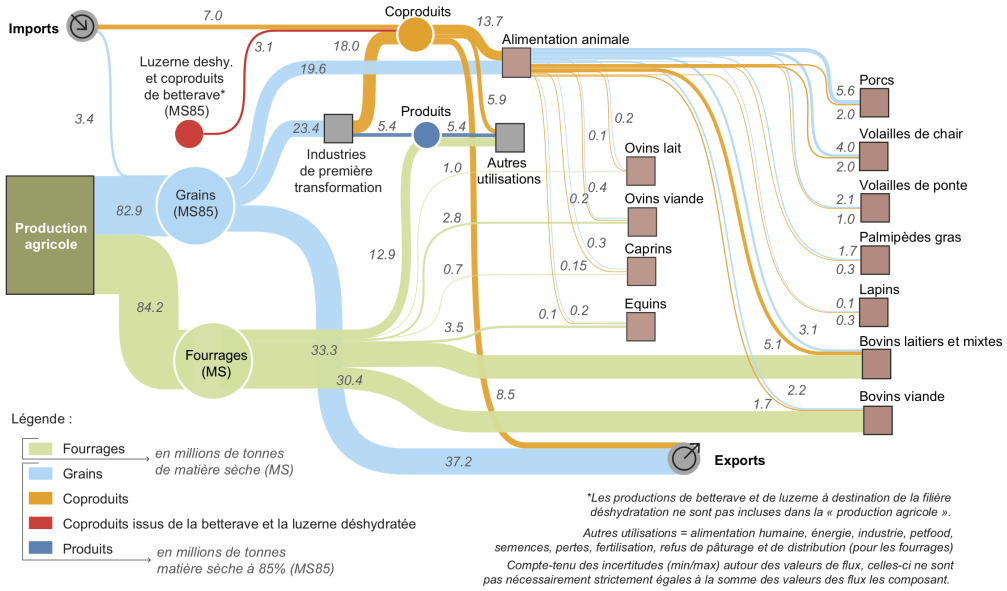

Figure 2: Sankey diagram of a supply chain (animal food production and supply).

  - 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.

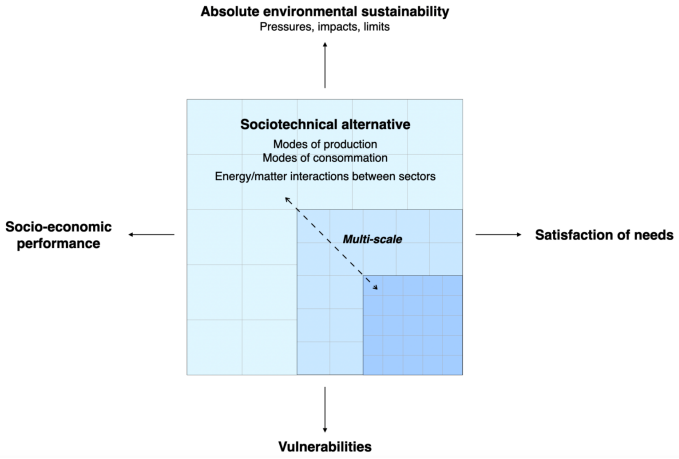

Figure 3: Schematic overview of research questions and concepts underlying sociotechnical alternatives. Center: targeted sociotechnical alternatives are typically of multi-scale nature. Borders: the four dimensions to be considered in evaluating sociotechnical alternatives (see text).

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 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[5] 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.

[5] Intergovernmental Panel on Climate Change, https://www.ipcc.ch/

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 8 years of age too). 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 (https://Campus1point5Grenoble.org/) and MakeSEns (https://hal.inria.fr/hal-02340948v1).

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 New software and platforms

6.1 New software

6.1.1 USAT

Name: Urban Sprawl Analysis Toolkit

Keywords: Urban sprawl, Urban planning

Functional Description: This software allows to calculate and analyse indices of urban sprawl from open data (OpenStreetMap), aimed to be used by urban scientists and urban planners. A spatialized version of indices measuring the accessibility, dispersion and land use mix is calculated. The implemented methods are described in [26].

News of the Year: In 2019 we started a refactoring of this software, together with an overhaul of the associated web service USAT-WEB. This activity continued in 2020.

URL: https://github.com/lgervasoni/urbansprawl

Contact: Peter Sturm

Participants: Luciano Gervasoni, Serge Fenet, Peter Sturm, Roger Pissard-Gibollet

Partner: LIRIS

6.1.2 USAT WEB

Name: Urban Sprawl Analysis Toolkit Web-service

Keywords: Urban planning, Urban sprawl

Functional Description: This is a web-service on top of the software USAT described above. The web-service will allow any user to select a region of interest and to launch the calculation and display of sprawl indices using USAT. It is in the process of being hosted on the HPC platform of IN2P3, after which it will be made open to the public. The source code for this web-service is already available at the below site.

The web-service is described in [33].

News of the Year: In 2019 we started a complete overhaul of this software, together with a factorization of the underlying computation core (USAT). This activity continued in 2020.

URL: https://gitlab.inria.fr/lrezakha/usat-web

Publication: hal-01610738

Contact: Peter Sturm

Participants: Lucas Rezakhanlou, Peter Sturm, Luciano Gervasoni, Serge Fenet, Roger Pissard-Gibollet

6.1.3 Comptabilité Ecologique

Keyword: Data visualization

Functional Description: Databases and online data visualization tools. Databases include socio-economic and environmental datasets. Visualization tools include interactive piecharts, maps and Sankey diagrams.

URL: http://www.eco-data.fr

Contact: Jean-Yves Courtonne

Participants: Jean-Yves Courtonne, Pierre-Yves Longaretti

6.1.4 REDEM

Name: REDuction Of EMission

Keyword: Climate change

Functional Description: REDEM soft is a tool designed for the benchmarking of national GHG emission reduction trajectories. The actual version of the software is implemented in Visual Basic under Microsoft Excel in order to facilitate handling and diffusion to climate/energy economists.

News of the Year: In 2020, the database underlying REDEM was updated with recent national emission trajectory information.

URL: http://redem.gforge.inria.fr/

Contact: Emmanuel Prados

Participants: Constantin Ilasca, Hélène Benveniste, Olivier Boucher, Patrick Criqui, Roger Pissard-Gibollet

Partners: EDDEN, IPSL

6.1.5 REDEM web

Name: REDEM Web

Keywords: Benchmarking, Climate change, Global warming, Greenhouse gas emissions

Functional Description: Python Library of REDEM model and its web application.

URL: http://redem.inria.fr/

Contact: Emmanuel Prados

Participants: Constantin Ilasca, Emmanuel Prados, Hélène Benveniste, Nicolas Assouad, Olivier Boucher, Patrick Criqui, Roger Pissard-Gibollet

Partners: UPMC, EDDEN

6.1.6 Layout of Sankey diagrams

Keywords: Data visualization, Visualization, Sankey diagram, Flow visualization

Scientific Description: A Sankey diagram is a visualization of sectors that are arranged in layers: in each layer, sectors are represented by nodes which are organized and aligned vertically. Flows are only possible between distinct layers, therefore they are mainly horizontally oriented. Each flow is represented by a graphic link (e.g. a Bézier curve) having a width corresponding to the flow volume. The main objective is to visualize an economic sector or another structure in the most efficient way, in other words the representation of the elements must facilitate human understanding of the structure. Literature offers several criteria which can be used and optimized to achieve this objective. This software generates Sankey diagrams automatically. The creation includes several steps, each of them focuses on the resolution of a specific optimization problem. The formulation of these is inspired by the article "Optimal Sankey Diagrams via Integer Programming" written by Zarate et al. in 2018. The software includes an implementation of this and several new methods. They are based on solving linear programming optimization problems.

Functional Description: A Sankey diagram is a type of visualization of flows (of data, physical entities, money, etc.) between sectors (for example, economic sectors). The main entries of the software are a table comprising a description of these sectors and the flows, as well as the flows' volume. The software contains functions that aim at computing an optimal disposition of the flow diagram (position of sectors and flows on the produced chart), according to different possible criteria. For instance, a disposition that minimizes the number of crossings between flows or that contains as horizontal as possible flows.

Contact: Peter Sturm

Participants: Joanna Maurin, Peter Sturm, Jean-Yves Courtonne, Julien Alapetite

6.1.7 Sankeytool

Name: Web app for drawing Sankey diagrams

Keywords: Data visualization, Visualization, Sankey diagram, Flow visualization

Scientific Description: A Sankey diagram is a visualization of sectors that are arranged in layers: in each layer, sectors are represented by nodes which are organized and aligned vertically. Flows are only possible between distinct layers, therefore they are mainly horizontally oriented. Each flow is represented by a graphic link (e.g. a Bézier curve) having a width corresponding to the flow volume. The main objective is to visualize an economic sector or another structure in the most efficient way, in other words the representation of the elements must facilitate human understanding of the structure. Literature offers several criteria which can be used and optimized to achieve this objective. This software generates Sankey diagrams automatically. The creation includes several steps, each of them focuses on the resolution of a specific optimization problem. The formulation of these is inspired by the article "Optimal Sankey Diagrams via Integer Programming" written by Zarate et al. in 2018. The software includes an implementation of this and several new methods. They are based on solving linear programming optimization problems.

Functional Description: The software is an online web app that allows manual and automatic sankey diagram plotting. Among the functions these diagrams can be exported in svg or pdf format.

A Sankey diagram is a type of visualization of flows (of data, physical entities, money, etc.) between sectors (for example, economic sectors). The main entries of the software are a table comprising a description of these sectors and the flows, as well as the flows' volume. The software contains functions that aim at computing an optimal disposition of the flow diagram (position of sectors and flows on the produced chart), according to different possible criteria. For instance, a disposition that minimizes the number of crossings between flows or that contains as horizontal as possible flows.

News of the Year: End of the AFM Filières project sponsored by Ademe. Beginning of incubation of the Terriflux company inside the startup studio program of Inria.

URL: http://www.flux-biomasse.fr

Contact: Jean-Yves Courtonne

Participants: Jean-Yves Courtonne, Julien Alapetite

6.1.8 Clumpy

Name: Comprehensive Land Use Models in Python

Keywords: Land use and cover change, LUCC, Spatially explicit model, Geostatistic, GIS

Functional Description: Clumpy is a land use and cover change model (a python package) which aims to be used in sustainability and environmental sciences. It allows to observe past changes statistics, set future contrasted scenarios and allocate simulated future land use maps according to those projections. From past land use maps and some explanatory variables, the software calibrates the model through machine learning methods (kernel density estimations, nearest neighbors for now). Explicit probabilistic values are returned and can be then adjusted to contrasted scenarios set by the user. It is finally possible to allocate a simulated land use map in order to provide decision materials for public stakeholder. Other land use and cover change model softwares such as Dinamica EGO, CLUE and LCM are compared to Clumpy in papers to come.

URL: https://gitlab.inria.fr/fmazy/clumpy/

Contact: François-Rémi Mazy

Participants: François-Rémi Mazy, Pierre-Yves Longaretti

6.1.9 SC-MFA

Name: Supply Chain Material Flow Analysis

Keyword: Optimisation

Scientific Description: The scientific methodology (described in detail in the thesis of Jean Yves Courtonne 2016) is summarized in the following. It consists of modeling, reconciliating and downscaling of flow data, typically flow data pertaining to supply chains. The existence of multiple units (physical units such as mass or volume, equivalence units, monetary, environmental pressures) is taken into account, enabling the fusion of environmental, monetary and supply assessments. The methodology takes also into account uncertainties and their reconciliation, allowing to highlight areas with poor information. The geographical downscaling ensures the coherence of results across territories and scales.

Functional Description: The software performs data reconciliation by constraints optimization. It works on Excel sheets and can be run through the command line or from a web application.

Release Contributions: No previous version. The program takes as input an excel file and the output is the same excel file, with supplementary sheets that contain the results of the processing (reconciliation, uncertainty handling, downscaling, etc.).

News of the Year: End of AFM Filières ademe project. Beginning of company Terriflux inside the startup studio program of Inria.

URL: http://www.flux-biomasse.fr

Contact: Jean-Yves Courtonne

Participants: Jean-Yves Courtonne, Julien Alapetite

Partner: Alapetite Julien

7 New results

7.1 Global systemic risks and risks of collapse – which elements of scientific analysis, for which types of risk?

Participant: Pierre-Yves Longaretti.

Collapsology is both a neologism and a movement, born in French-speaking countries with the publication of Pablo Servigne and Raphaël Stevens' book, "Comment tout peut s'effondrer", in 2015. For many, this book marked the eruption of the question of the risks of collapse of our globalized society into the public debate. At the same time, the notion as well as the movement crystallized sometimes contradictory affects, and varied criticisms often dealing with a deficiency of political analysis in the collapsological discourse. The term collapsology seems to refer to a scientific discipline. But if there are many elements of scientific analysis informing on the risks of collapse, they do not belong to a structured academic field. Although these elements partially underlie Servigne and Stevens' book, the scientific status of the issue does not seem to be properly understood, either in public opinion, among collapsology sympathizers, or in the minds of many decision makers. Faced with this observation, we present a brief overview of the scientific state of the art on collapse risks and its level of reliability, based on a few key works and publications from the various disciplines concerned [14].

7.2 Gross vs. net energy of oil liquids at global scale: the reconsideration of peak oil

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

Since the 1859's Pennsylvania rush, oil quickly grew to be the dominant fuel of industrial society and is today the backbone of most advanced economies. The "Peak Oil" debate focused on whether or not there was an impending production crunch of cheap oil, and though there hasn't been widespread shortages across the globe, a transition in quality from conventional to unconventional oil liquids occurred. One aspect of this transition that was not fully explored in the previous discussions was whether the net energy supply will be impacted by the use of lower quality energy sources. To fill this gap, this paper incorporates standard EROI (energy-return-on-investment) estimates and associated decline functions to the GlobalShift all-liquids bottom-up model at global scale. We find that accounting for the cost of energy acquisition not only indicates a sooner peak by 3 years and a reduced production level at the peak of 17% but also–and perhaps more importantly, a ratio between the decline and the incline rates 2.5 greater compared to gross energy, with robust results. We therefore prompt for an urgent return of the peak oil debate in a novel form, foreshadowing the danger of focusing on the peak supply vs. peak demand dispute. This work has been submitted to *Ecological Economics*.

7.3 Economic growth, decoupling, and greenhouse gas: numerical targets and laws of physics

Participants: Pierre-Yves Longaretti, Benoît Schmaltz (Univ Toulouse I).

The pursuit of a global economic growth objective of around 2% per year is only compatible with the Paris Agreement objectives of limiting global warming by the end of the century by $2^{\circ}C$ through a decoupling between energy use and greenhouse gas emissions. In the optimistic hypothesis of a peak in emissions in 2025, this decoupling must be of the order of 10 to 12% per year for at least ten years, compared to the trend, which is only 1%/year. From an engineering point of view, such a decoupling is a challenge, if not an impossibility. From a legal point of view, it must be noted that positive law, reflecting the political will, postulates such an unlikely decoupling. This calls for criticism and reflection on the difficulty of a legal coupling between economic policy instruments and climate policy instruments, which implies a profound conceptual revolution at the confluence of ecology, economics and law.

This work was presented at the *Colloque Chiffre(s) et Droit Public* in Lyon, October 2020 and is to be published in 2021.

7.4 Analyzing territorial metabolism to characterize the vulnerability and capabilities of wealth creation activities in the French Alps Maurienne valley

Participants: Michela Bevione, Jean-Yves Courtonne, Quentin Desvaux, Pierre-Yves Longaretti, Nicolas Buclet (PACTE Laboratory, Univ Grenoble Alpes).

Alpine valleys constitute fragile environments and are very sensitive to environmental change. Current trends constitute major upheavals challenging these communities' adaptation abilities. Coupling quantitative modeling and qualitative social sciences analyses is necessary to provide insights on vulnerability issues but such endeavors remain scarce in the scientific literature.We present an analysis framework designed to address the issue at local levels and describe local communities and their environment as a network of wealth creation activities. This method integrates a qualitative socio-ecosystem interpretative framework, with quantitative territorial metabolism analyses and associated environmental and economic stakes in order to pinpoint key vulnerabilities. We introduce the concept of 'territorial capability', and use it to analyze the ability of stakeholders to cope with change through a reorientation of their activities. We apply the preceding generic framework to one of the main farming activities in the Alpine valley of Maurienne, the production of Beaufort cheese. We describe how each stakeholder is involved in the supply chain and then quantify the economic and environmental aspects of the value. This information helps identifying vulnerabilities of the Maurienne dairy chain. While current environmental pressures do not seem to overshoot local environmental limits, climate change is likely to be a source of future vulnerability. The analysis also underlines the dependence to subsidies and threats on the renewal

of the workforce. The cooperatives system appears to be the cornerstone of territorial capability. Finally, we discuss empirical and theoretical limits of the study and future research leads. This work has been submitted to *Regional Environmental Change*.

7.5 Material Flow Analysis for agricultural modeling – towards the scenarization of sociotechnical alternatives

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

Material Flow Analysis (MFA) is a central tool in the team, especially in the Sociotechnical Alternatives axis. In [20], we describe research done to study agricultural metabolisms in the MFA framework. More precisely, we were interested in studying perturbations of the nitrogen cycle (which is considered as one of the 9 planetary boundaries and one of 4 already broken [34]) and in examining the food competition between humans and animals (cattle). Towards these ends, we first established an MFA based on [22, 23] and data available in various other sources. We then started to develop a modular representation of MFA's. The goal is to propose modules from which MFA's can be composed (for instance modules for cattle breeding or cereal production), modules that can be calibrated from dedicated data and "driven" by parameters of main interest, for instance the type of agricultural production or the size of a herd. The ultimate goal is to scenarize sociotechnical alternatives, which might be "controlled" by higher-level parameters, such as basic needs to be fulfilled, type of food diet, etc. and which will be connected to the modules' parameters. To do so, interactions between modules need to be handled, such as between cattle breeding and fodder production: cattle eat fodder (e.g. through grazing) and their excretions are an essential "fertilizer" for pastures producing fodder. We proposed a first specification of such interconnected modules.

7.6 Material and Energy Flows of the French Economy – Case study of NegaWatt and Ademe's scenarios

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

In [18] we propose a first methodology to allow to represent by intervals flows whose information is difficult to collect and also to gather data under the same formalism by merging available expertise to create a single supply–use table at the desired scale. This work is part of a project that wishes to build a national physical table of our economy. However, its creation is not the only objective; we wish to work on the multi-scale aspect of this table, i.e. to be able to descend from the national to the regional, or even infra-regional level. A medium-term objective is to use the formalism and methods presented in participatory territorial foresight exercises, for example to scenarize alternative economic arrangements in a territory and evaluate them according to criteria of sustainability or resilience. This is therefore the first step towards a multi-scale environmental assessment of our economy. In [18] we apply the above mentioned methodology to energy transition scenarios. NegaWatt is a scenario for energy transition of France developed by an independent association with the same name. This association gathers about twenty experts involved in professional activities linked to the energy sector. In 2003, they published their first scenario which aims to zero greenhouse gas emission in 2050. Since this first one, they publish new scenario updates every five years. The scenario is based on several hypotheses about the consumption and production of energy in France from now to 2050. For this work, we were only interested in two years, 2015 and 2050. Indeed to produce a sociotechnical alternative, target end-states and data are needed. Those two years give us both. Our first work was thus to express those scenarios into our formalism (MFA, see previous section). Then, thanks to the NegaWatt's partners, we were able to have access to a report from Ademe (the French agency for Ecological Transition) which publishes several reports about sectors closely linked to pollution or natural resources and proposes various expert assessment on the environment. This report [32] proposes a focus on the physical quantities in the current economy with a prospective part. Indeed, the focus is on nine materials and six sectors that consume the most energy in France. We chose one sector (building sector) and two materials (steel and clinker) plus the energy sector [6] to analyze and to integrate into our formalism. These sectors and materials were chosen because they

[6] http://www.negawatt.org/scenario/sankeys/2015

are linked to one another and are central in the energy transition debate (e.g. renovation and insulation policies). We thus extracted and put into our formalism the data from the Ademe report for each sector and material and managed to carry out a global data reconciliation. This work, together with the one described in the previous section, is a building block of our general project on modeling the complete economy of France and of designing and later evaluating, sociotechnical alternatives for the future.

7.7 Modeling tools for sociotechnical systems

Participants: Charlie Dworaczek, Jean-Yves Courtonne, Guillaume Mandil.

As climate change invites us to a profound adaptation of our society, the imagination of new systems, called sociotechnical alternatives, is a particularly pressing problem. Generally, a sociotechnical system is a network linking actors with economic, material, cultural or social links. While most of our works on sociotechnical alternatives are concerned with economic and material aspects having a "physical" representation, it is equally (if ultimately not more) important to also take into account social, cultural and political aspects. In [19], we explored the usage of the SysML language in order to produce hybrid representations of sociotechnical systems, of both "physical" and such other aspects (in particular, the interplay of stakeholders of a local economy).

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

Contract with **ADEME** (French Environment and Energy Management Agency [7]), within a collaboration with FCBA [8], Arvalis [9], Terres Univia [10], and Terres Inovia [11]. Design and development of an interactive spreadsheet application for scenarizing non-food biomass flows in France, from production to consumption (energy and non-energy uses). Visualization in the form of Sankey diagrams.

Contract with **Aura-EE** (Energy and Environment Agency of the Auvergne–Rhône-Alpes Region [12]), within the Interreg Alpine Region program. Estimation of material flows within the wood supply chain in the Alps European Region.

Contract with **Aura-EE** within the European project IMEAS. Estimation of wood flows between the Vercors Regional Natural Parc and the Grenoble metropolitan area.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Inria international partners

Informal international partners Serge Fenet is involved in a collaboration with the University of Lausanne (UNIL), Department of Ecology and Evolution (Jérôme Gippet), working on the development of the MoRIS model of propagation of invasive species.

Serge Fenet is involved in the TRAJECLIM project with the Laboratoire Ecologie Fonctionnelle et Environnement of Toulouse INP, that focuses on the resilience of the current trajectory of a polar socio-ecological system facing climate and anthropogenic change.

9.1.2 Participation in other international programs

Pierre-Yves Longaretti is involved in TARA (Transition adaptation research alliance).

[7] https://www.ademe.fr/en
[8] https://www.fcba.fr
[9] https://www.arvalisinstitutduvegetal.fr/gis-@/view-607-arvstatiques.html
[10] http://www.terresunivia.fr
[11] https://www.terresinovia.fr
[12] https://en.auvergnerhonealpes-ee.fr

9.2 National initiatives

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

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 transfering 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.

9.3 Regional initiatives

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

Project funded by ADEME, Grenoble metropolis, IDEX Université Grenoble Alpes
Duration: 2016–2022
Project coordinator: Remy 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.

10 Dissemination

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

This year we have started the organization of a conference on systemic risks, trajectories and levers of action, https://oasis.inria.fr/. The conference is scheduled for march 2022. The main objective is to launch a collaborative effort aimed at:

- gathering a community of scientists from various fields who adopt systemic approaches on global challenges;
- co-constructing and consolidating frames of thought, knowledge and methodologies on global systemic risks, their evaluation and mitigation;
- advancing the creation and dissemination of knowledge.

The first edition of the conference will be french-speaking. We hope that this event turns into a regular and potentially international one.

The overall organization is carried out by STEEP. The scientific committee will be chaired by Pierre-Yves Longaretti and the steering committee is composed by Serge Fenet, Mathieu Mangeot, and Emmanuel Prados.

Member of the editorial boards Since september 2020, Guillaume Mandil is editorial manager of the web site of "L'encyclopédie de l'energie": https://www.encyclopedie-energie.org/qui-sommes-nous/

Reviewer - reviewing activities Jean-Yves Courtonne was a reviewer for the Futures journal.

10.1.2 Invited talks

Peter Sturm gave a keynote presentation at the annual conference of the European Research Programme CHIST-ERA, entitled "Some General Considerations on Sustainable ICT".

10.1.3 Scientific expertise

- Emmanuel Prados is one of the lead authors of the "white book" (*livre blanc*) on the use of digital technologies in agriculture. The white book is co-produced by Inrae (French National Research Institute for Agriculture, Food and Environment) and Inria and is scheduled to appear in 2021. A preliminary presentation has been given in [15].
- Guillaume Mandil is member of the scientific committee of the "Parc Naturel Régional de Chartreuse" since september 2020. https://www.parc-chartreuse.net/comprendre-le-parc/le-fonctionnement-du-parc/instances-de-concertation/
- Emmanuel Prados and Jean-Yves Courtonne are members 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 Terristory consortium (http://terristory.fr).
- 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 is one of the rapporteurs. Jean-Yves Courtonne and Peter Sturm participated in the round table of the workshop on Territorial souvereignty and resilience. https://www.allianceenergie.fr/energie-decarbonee-changement-climatique-sante-environnementale-biodiversite/
- Jean-Yves Courtonne acted as expert for calls of the Nouvelle-Aquitaine region and the LabEx ARBRE.
- Pierre-Yves Longaretti is member of the scientific committee of the FEE (Fondation d'Economie Environnementale, Grand Annecy)
- Jean-Yves Courtonne and Guillaume Mandil participate in the Steering Committee (COPIL) of the CODEC (*Contrat d'Objectifs Déchets et Économie Circulaire*) of Grenoble Alpes Métropole (Grenoble Metropolitan Area, https://www.lametro.fr/).

10.1.4 Research administration

- Emmanuel Prados and Guillaume Mandil are members of the Campus1point5Grenoble initiative: an international, cross-disciplinary collective of academic researchers who share a common goal: to better understand and reduce the environmental impact of research, especially on the Earth's climate, https://Campus1point5Grenoble.org/
- Peter Sturm was Deputy Scientific Director of Inria, in charge of the domain Perception—Cognition—Interaction, from 2015 until september 2020.
- 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).

10.2 Teaching - Supervision - Juries

10.2.1 Teaching

- 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, L3 Computer science, UGA.
- Jean-Yves Courtonne and Emmanuel Prados: course in the "Green University program" of UGA, 4h of course and 10h of student project supervision.
- Peter Sturm taught a session on "Environmental challenges and what is blocking acting on them" at T-Camp (Transition Camp, training program organized by the *Campus de la Transition*, Forges, France, May 2020.
- Pierre-Yves Longaretti taught a session on "Global change, global planetary limits and global systemic risks" at T-Camp (Transition Camp, training program organized by the *Campus de la Transition*, Forges, France, May 2020.
- Serge Fenet taught a 12h session on "Anthropocène : une histoire de systèmes en transition" at the MSc. in Strategy & Design for the Anthropocene of the ESC of Clermont.
- Denis Dupré, Serge Fenet, Guillaume Mandil and Régis Perrier have regular teaching duties at the universities employing them.

10.2.2 Supervision

- PhD in progress: Michela Bevione, *Enjeux socio-écologiques, métabolisme territorial, création de richesse : application à la vallée de la Maurienne*, started in October 2016, supervised by Pierre-Yves Longaretti and Nicolas Buclet (PACTE laboratory)
- 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, supervised by Catherine Figuière (CREG), Guillaume Mandil, Jean-Yves Courtonne.

- PhD in progress: Mathilde Jochaud du Plessix, *Analyse de la robustesse et de la validité des modèles dynamiques de risques systémiques globaux*, supervised by Emmanuel Prados, Serge Fenet and Pierre-Yves Longaretti
- PhD in progress: Olivier Mauviel, *Méthodologie 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

10.2.3 Juries

- Peter Sturm chaired the Habilitation committee of Sylvie Chambon (Université de Toulouse) and was member of the PhD thesis committee of Lucas Foulon (Université de Lyon).

10.3 Popularization

10.3.1 Education

- Emmanuel Prados, Pierre-Yves Longaretti, Guillaume Mandil along with Grégoire Chambaz, launched the project Anthropocene FACTS. On the long run, this project aims to produce educational content on the trajectories of modern societies in the Anthropocene. 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 Summer School, which is scheduled to take place in late August 2021. To date, the scientific committee of the project is constituted of: Bert De Vries (University of Utrecht), Claude Mandil (https://fr.wikipedia.org/wiki/Claude_Mandil), Patrick Criqui (University Grenoble Alps), David Korowicz (Geneva Global Initiative), Guy Middleton (Newcastle University), Amy Dahan (https://fr.wikipedia.org/wiki/Amy_Dahan), Stefan Giljum (Vienna University of Economics and Business)
- Peter Sturm presented the profession of scientist to pupils of two middle schools (*collèges* of Villard-Bonnot and Crolles), February 2020.
- Emmanuel Prados made interventions on the theme of the environment and the digital in the Jean Vilar Collège of Échirolles in front of 4 classes of 5th grade, February 2020.

10.3.2 Interventions

- Jean-Yves Courtonne helped Pauline Tardy-Galliard (from Inria Grenoble's communication and mediation service) preparing her radio intervention on France Bleu Isère about the Terristory platform (https://www.francebleu.fr/emissions/la-carte-blanche-a/isere/la-carte-blanche-a-146).
- Guillame Mandil gave an interview on France Culture on 29th September 2020 (https://www.franceculture.fr/emissions/entendez-vous-leco/entendez-vous-leco-emission-du-mardi-29-septembre-2020)
- Peter Sturm participated in the round table on "The role of scientists in the face of environmental challenges", organized by Inria within the annual *Fête de la Science*, October 2020.
- Team members gave the following general audience talks:
  - Emmanuel Prados and Pierre-Yves Longaretti gave a conference entitled "Towards a collapse of our modern society?" at the Néel Institute (CNRS, Grenoble), January 2020. http://sfp.grenoble.cnrs.fr/spip.php?page=evenement&id_evenement=6143

– Denis Dupré gave a conference in the “Comprendre et Agir” cycle on the theme “Collapse and Finance”, entitled “Finance: firemen of collapses?”, January 2020. https://www.youtube.com/watch?v=7on_mou174E

– Peter Sturm: "Environmental challenges and what is blocking acting on them", ATD Quart Monde (association dedicated to the eradication of poverty), France, June 2020.

– Peter Sturm: "Environmental challenges and what is blocking acting on them", Université de Bourgogne, Le Creusot, France, June 2020.

10.4 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 2020 the YouTube channel has about 7,300 subscribers and reached a total of about 610,000 viewings.

The conference-debates of 2020 (for obvious reasons, several planned conference-debates had to be postponed, leading to a reduced program this year):

- Denis Dupré (STEEP): *Effondrements et finance (partie II) – Les finances : pompier des effondrements ?*, january 23, 2020, https://team.inria.fr/steep/seminars/les-conferences-debats-comprendre-et-agir/#conf23
- Cécile Renouard (Centre Sèvres): *Pensée et pratique de l’action – “Comprendre pour agir, se former pour transformer”*, october 8, 2020, https://team.inria.fr/steep/seminars/les-conferences-debats-comprendre-et-agir/#conf29
- Asma Mhalla (SciencesPo Paris): *Les nouveaux pouvoirs à l’ère de l’intelligence artificielle : Qui gouvernera le monde au XXIème siècle ?*, october 23, 2020, https://team.inria.fr/steep/seminars/les-conferences-debats-comprendre-et-agir/#conf24

Link to the web page of the series (program, abstracts, dates, complements etc.): https://team.inria.fr/steep/les-conferences-debats-comprendre-et-agir/

Link to the YouTube channel: https://www.youtube.com/channel/UCJbcXCcOA63M8VMysAbmt_A

11 Scientific production

11.1 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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[19] C. Dworaczek. 'Etude d'outils de modélisation des systèmes socio-techniques'. Université lyon 1, 16th Sept. 2020. URL: https://hal.inria.fr/hal-03024784.

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