IN PARTNERSHIP WITH:
CNRS

Université de Grenoble Alpes

Activity Report 2019

Project-Team STEEP

Sustainability transition, environment, economy and local policy

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Earth, Environmental and Energy Sciences

Table of contents

Project-Team STEEP

Creation of the Team: 2010 January 01, updated into Project-Team: 2015 December 01

Keywords:

Computer Science and Digital Science:

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
B3.4.3. - Pollution
B7. - Transport and logistics
B8.3. - Urbanism and urban planning
B8.5.1. - Participative democracy
B8.5.3. - Collaborative economy
B9.9. - Ethics

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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" of Inria Grenoble - Rhône-Alpes and is also affiliated with the Jean Kuntzmann laboratory (LJK [1]).

STEEP is an interdisciplinary research team devoted to systemic modelling and simulation of the interactions between the environmental, economic and social factors in the context of a transition to sustainability at local (sub-national) scales. Our goal is to develop decision-making tools to support decision makers in the implementation of this transition by developing simulation and optimization programs. In other words, our objective is to set up some mathematical and computational tools which enable us to provide some parts of the answer to the challenges *how to operate the sustainable development at local scales? and which local governance for environmental public policies?*.

The work of STEEP follows several research directions, covering different application domains; these are described in "Scientific Foundations" and "Application Domains" respectively.

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, important 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 strengthened 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.

[1] http://ljk.imag.fr/

Although environmental challenges are monitored worldwide, the search for appropriate lines of actions must nevertheless take place at all institutional levels, in particular at local scales. At such scales, the proximity and smaller number of stakeholders allows decision makers to reach a consensus much more easily than at national or international scales. The failure of the recent Copenhagen summit (and for that matter of all climate summits since the adoption of the Kyoto protocol in 1997) is 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 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 areas of main cities) and “regions” (such as régions in France, Lander 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 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-fourths 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.

[2] http://www.gmo-free-regions.org

[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.

STEEP, with its strong background in various areas of applied mathematics and modeling, can be a game changer in three connected key domains: urban economy, and related transportation and land use issues; material flow analysis and ecological accounting; and ecosystem services modeling. The group potential on these fronts relies on its capabilities to strongly improve existing integrated activity / land use / transportation models at the urban level on the one hand, and on the other, to build new and comprehensive decision-help tools for sustainability policies at the local and regional levels, in particular through the analysis of strategic social–environmental trade-offs between various policy options.

3. Research Program

3.1. Development of numerical systemic models (economy / society / environment) at local scales

The problem we consider is intrinsically interdisciplinary: it draws on social sciences, ecology or science of the planet. The modeling of the considered phenomena must take into account many factors of different nature which interact with varied functional relationships. These heterogeneous dynamics are *a priori* nonlinear and complex: they may have saturation mechanisms, threshold effects, and may be density dependent. The difficulties are compounded by the strong interconnections of the system (presence of important feedback loops) and multi-scale spatial interactions. Environmental and social phenomena are indeed constrained by the geometry of the area in which they occur. Climate and urbanization are typical examples. These spatial processes involve proximity relationships and neighborhoods, like for example, between two adjacent parcels of land, or between several macroscopic levels of a social organization. The multi-scale issues are due to the simultaneous consideration in the modeling of actors of different types and that operate at specific scales (spatial and temporal). For example, to properly address biodiversity issues, the scale at which we must consider the evolution of rurality is probably very different from the one at which we model the biological phenomena.

In this context, to develop flexible integrated systemic models (upgradable, modular, ...) which are efficient, realistic and easy to use (for developers, modelers and end users) is a challenge in itself. What mathematical representations and what computational tools to use? Nowadays many tools are used: for example, cellular automata (e.g. in the LEAM model), agent models (e.g. URBANSIM [5]), system dynamics (e.g. World3), large systems of ordinary equations (e.g. equilibrium models such as TRANUS), and so on. Each of these tools has strengths and weaknesses. Is it necessary to invent other representations? What is the relevant level of modularity? How to get very modular models while keeping them very coherent and easy to calibrate? Is it preferable to use the same modeling tools for the whole system, or can we freely change the representation for each considered subsystem? How to easily and effectively manage different scales? (difficulty appearing in particular during the calibration process). How to get models which automatically adapt to the granularity of the data and which are always numerically stable? (this has also a direct link with the calibration processes and the propagation of uncertainties). How to develop models that can be calibrated with reasonable efforts, consistent with the (human and material) resources of the agencies and consulting firms that use them?

Before describing our research axes, we provide a brief overview of the types of models that we are or will be working with. As for LUTI (Land Use and Transportation Integrated) modeling, we have been using the TRANUS model since the start of our group. It is the most widely used LUTI model, has been developed since 1982 by the company Modelistica, and is distributed *via* Open Source software. TRANUS proceeds by solving a system of deterministic nonlinear equations and inequalities containing a number of economic parameters (e.g. demand elasticity parameters, location dispersion parameters, etc.). The solution of such a system represents an economic equilibrium between supply and demand.

[5] http://www.urbansim.org

On the other hand, the scientific domains related to ecosystem services and ecological accounting are much less mature than the one of urban economy from a modelling point of view (as a consequence of our more limited knowledge of the relevant complex processes and/or more limited available data). Nowadays, the community working on ecological accounting develops statistical models based on the enforcement of the mass conservation constraint for accounting for material fluxes through a territorial unit or a supply chain, relying on more or less simple data correlations when the relevant data is missing; the overall modelling makes heavy use of more or less sophisticated linear algebra and constrained optimization techniques. The ecosystem service community has been using statical models too, but is also developing more sophisticated models based for example on system dynamics, multi-agent type simulations or cellular models. In the ESNET project, STEEP has worked in particular on a land use/land cover change (LUCC) modelling environments (Dinamica [6]) which belongs to the category of spatially explicit statistical models.

In the following, our two main research axes are described, from the point of view of applied mathematical development. The domains of application of this research effort is described in the application section, where some details about the context of each field is given.

3.2. Model calibration and validation

The overall calibration of the parameters that drive the equations implemented in the above models is a vital step. Theoretically, as the implemented equations describe e.g. socio-economic phenomena, some of these parameters should in principle be accurately estimated from past data using econometrics and statistical methods like regressions or maximum likelihood estimates, e.g. for the parameters of logit models describing the residential choices of households. However, this theoretical consideration is often not efficient in practice for at least two main reasons. First, the above models consist of several interacting modules. Currently, these modules are typically calibrated independently; this is clearly sub-optimal as results will differ from those obtained after a global calibration of the interaction system, which is the actual final objective of a calibration procedure. Second, the lack of data is an inherent problem.

As a consequence, models are usually calibrated by hand. The calibration can typically take up to 6 months for a medium size LUTI model (about 100 geographic zones, about 10 sectors including economic sectors, population and employment categories). This clearly emphasizes the need to further investigate and at least semi-automate the calibration process. Yet, in all domains STEEP considers, very few studies have addressed this central issue, not to mention calibration under uncertainty which has largely been ignored (with the exception of a few uncertainty propagation analyses reported in the literature).

Besides uncertainty analysis, another main aspect of calibration is numerical optimization. The general state-of-the-art on optimization procedures is extremely large and mature, covering many different types of optimization problems, in terms of size (number of parameters and data) and type of cost function(s) and constraints. Depending on the characteristics of the considered models in terms of dimension, data availability and quality, deterministic or stochastic methods will be implemented. For the former, due to the presence of non-differentiability, it is likely, depending on their severity, that derivative free control methods will have to be preferred. For the latter, particle-based filtering techniques and/or metamodel-based optimization techniques (also called response surfaces or surrogate models) are good candidates.

These methods will be validated, by performing a series of tests to verify that the optimization algorithms are efficient in the sense that 1) they converge after an acceptable computing time, 2) they are robust and 3) that the algorithms do what they are actually meant to. For the latter, the procedure for this algorithmic validation phase will be to measure the quality of the results obtained after the calibration, i.e. we have to analyze if the calibrated model fits sufficiently well the data according to predetermined criteria.

To summarize, the overall goal of this research axis is to address two major issues related to calibration and validation of models: (a) defining a calibration methodology and developing relevant and efficient algorithms to facilitate the parameter estimation of considered models; (b) defining a validation methodology and developing the related algorithms (this is complemented by sensitivity analysis, see the following section).

[6] http://www.csr.ufmg.br/dinamica/

In both cases, analyzing the uncertainty that may arise either from the data or the underlying equations, and quantifying how these uncertainties propagate in the model, are of major importance. We will work on all those issues for the models of all the applied domains covered by STEEP.

3.3. Sensitivity analysis

A sensitivity analysis (SA) consists, in a nutshell, in studying how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model inputs. It is complementary to an uncertainty analysis, which focuses on quantifying uncertainty in model output. SA's can be useful for several purposes, such as guiding model development and identifying the most influential model parameters and critical data items. Identifying influential model parameters may help in divising metamodels (or, surrogate models) that approximate an original model and may be simulated, calibrated, or analyzed more efficiently. As for detecting critical data items, this may indicate for which type of data more effort must be spent in the data collection process in order to eventually improve the model's reliability. Finally, SA can be used as one means for validating models, together with validation based on historical data (or, put simply, using training and test data) and validation of model parameters and outputs by experts in the respective application area.

The first two applications of SA are linked to model calibration, discussed in the previous section. Indeed, prior to the development of the calibration tools, one important step is to select the significant or sensitive parameters and to evaluate the robustness of the calibration results with respect to data noise (stability studies). This may be performed through a global sensitivity analysis, e.g. by computation of Sobol's indices. Many problems had been to be circumvented e.g. difficulties arising from dependencies of input variables, variables that obey a spatial organization, or switch inputs. We take up on current work in the statistics community on SA for these difficult cases.

As for the third application of SA, model validation, a preliminary task bears on the propagation of uncertainties. Identifying the sources of uncertainties and their nature is crucial to propagate them via Monte Carlo techniques. To make a Monte Carlo approach computationally feasible, it is necessary to develop specific metamodels. Both the identification of the uncertainties and their propagation require a detailed knowledge of the data collection process; these are mandatory steps before a validation procedure based on SA can be implemented. First, we focus on validating LUTI models, starting with the CITiES ANR project: here, an SA consists in defining various land use policies and transportation scenarios and in using these scenarios to test the integrated land use and transportation model. Current approaches for validation by SA consider several scenarios and propose various indicators to measure the simulated changes. We work towards using sensitivity indices based on functional analysis of variance, which allow us to compare the influence of various inputs on the indicators. For example it allow the comparison of the influences of transportation and land use policies on several indicators.

3.4. Global systemic risks

Modern societies are characterized by a very high level of global interconnections between many sectors of economic, social and political activity, as well as by the environmental impacts produced by these activities and their consequences for human societies themselves. The resulting generalized interdependences induce intrinsic, or "systemic", risks of instability. These risks constitute serious threats for the global socio-ecological system, and the issue of a potential global collapse is part of the threats to be analyzed.

Global systemic risks directly relate to the STEEP team project, i.e., the question of sustainability at various spatial scales. The ability of socio-ecosystems, local communities, nation States and the international community to address these risks is a key factor in a sustainability perspective. However, the topic of global systemic risks was not until recently within the scope of the research activity of the team.

Within academia, the activity of several research institutes is devoted to these risks, with a strong contribution of social sciences. The most representative are probably the *Global Systemic Risk Institute* of Princeton [7], the

[7] https://risk.princeton.edu/

Center for Risk Studies of Cambridge (UK) Cambridge [8], and the *Risk Center* of Zürich [9]. Various teams are also active on these themes, but with a more sectorial focus.

From the point of view of the main processes at work, global systemic risks can be grouped into two categories

1. Risks related to long term mean trends (several decades). For the most part, they are generated by the growing tension between our use of resources and pollution production and our (semi)-natural environment capacity to absorb the associated impacts. They also emerge from the back-reaction of these environmental changes on socio-ecosystems. These risks are underlined and amplified by specific historical, socio-politic and economic dynamics.
2. Risks related to systemic contagion effect, on much shorter terms (weeks or months), but sporadic and random. This type of risk is directly driven by the high level of interconnection of various large scale human activities, to intrinsic instabilities whose very existence is directly tied to these interconnections, and to the potential propagation of these instabilities in all sectors of activity, in a domino-like effect. These risks are amplified by current geopolical dynamics and by the deepening of the various environmental crises.

In such a context, and due to its areas of expertise, the STEEP team has a nearly unique ability and opportunity to make a significant contribution to these questions, most particularly on the modelling front.

The World3 model is without any doubt the most representative of the first category of risks. It was developed by Meadows and coworkers for their famous report on the limits to growth [18], [20]. The reinvestigation by [22], [23] and re-discussion by [13] have renewed the interest for this model, while raising more pinpointed questions on the robustness and validity of the conclusions drawn from it. We have started to address these questions on three different fronts:

1. Through an analysis of the parameterization choices performed in the mode. In practice the team has undertaken a sensitivity analysis that is substantially more comprehensive than previous attempts in this direction.
2. Through an analysis of the modelling choices performed by the Meadows group. This will consist in a partial sectoral and spatial disaggregation of the model.
3. Through some elements of epistemological analysis.

As a matter of fact, two internships have already been devoted to the sensitivity analysis of the model. This is now pursued through a PhD thesis, started last Fall. The student (Mathilde Duplessix) will also address the other two points in the course of her PhD.

The main practical interest of this work is related to the possibility of distinguishing a potential onset of collapse in the first or second half ot the century. These two broad options imply different mitigation/adaptation strategies, that need to be correctly anticipated.

On the front of systemic contagion risks, and although a comprehensive analysis of the whole range of potential risks is impossible in an exploratory phase, the nexus energy/finance/supply chains plays a particular role in our societies and present a specific level of criticity. Some sectorial (and even cross-sectorial) aspects of this nexust have been discussed in the literature (e.g., [16], [17], [14]), but apparently no global, generic has been produced so far. Such a model would constitute by itself a remarkable breakthrough in this topic.

Funding for these research objectives has been obtained this year, in the form of an Inria “Action Exploratoire” project which officially starts in January 2020. This funding covers a PhD (Louis Delannoy, starting in January 2020) and a post-doctoral position (scheduled to start in 2021).

4. Application Domains

[8] https://www.jbs.cam.ac.uk/faculty-research/centres/risk/
[9] https://riskcenter.ethz.ch/

4.1. Introduction

In the context described in the previous sections, we can distinguish two connected and complementary strategies for analyzing environmental pressures: a sectorial approach and a spatial one. The first one is more directly connected to ecological accounting, the second one has more direct relations to urban economy and land cover modelling. We start by describing the former.

4.2. Ecological accounting for sectorial pressure assessment

One of the major issues in the assessment of the long-term sustainability of urban areas is related to the concept of "imported sustainability". Cities 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 urban areas 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. Four methods stand out:

- Material Flow Analysis (MFA)
- Input-Output Analysis (IOA)
- Life-Cycle Analysis (LCA)
- Ecological Footprint (EF)

Each of these is based on a well-defined structuring element: mass conservation for MFA, measure of industrial inter-dependencies for IOA, identification of all the steps from cradle to grave for LCA, measure of biocapacity demand for EF. The different methods have preferred areas of application. For example, EF is more relevant for analyzing primary production such as agricultural staples, wood, etc. IOA is more focused on whole industrial sectors, while LCA is geared towards end-user products, taken as functional units; finally, primary materials (such as metals), waste and emissions are more easily characterized through MFA. Methodological choices are driven by the type of question one needs to address, data availability and collection method and the spatial scales under consideration. Indeed, data can be used in two different ways: bottom-up or top-down. The bottom-up data is more precise, but in general precludes comprehensiveness; on the contrary, the top-down data is by nature more comprehensive, but is not suited for a detailed, fine-scale analysis of the results.

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.

4.3. 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).

4.3.1. Land Use/Land Cover Change models (LUCC)

LUCC 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 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 Land Use/Land Cover Change (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.

4.3.2. Models for Land-Use and Transportation Interactions (LUTI)

Urban transport systems are intricately linked to urban structure and activities, i.e., to land use. Urbanization generally implies an increased travel demand. Cities have traditionally met this additional demand by extending transportation supply, through new highways and transit lines. In turn, an improvement of the accessibility of ever-farther land leads to an expansion of urban development, resulting in a significant feedback loop between transportation infrastructure and land use, one of the main causes of urban sprawl. Transportation models allow us to address questions generally limited to the impacts of new infrastructures, tolls and other legislation on traffic regulation [10], on user behavior [11], or on the environment [12]. LUTI models (Land-Use and Transport Integrated models) can answer a much broader spectrum of issues. For example, they allow us to understand how the localization of households and of economic activities (which generate transportation demand) adapt to changes of transportation supply. They also allow us to assess the impacts of such changes on the increase in real estate value, or more generally on their effects on the economic development of a specific sector or neighborhood. An economic vision interprets all these interactions in terms of equilibrium between demand and supply. Modelling the localization of households and employments (companies) relies on capturing the way stakeholders arbitrate between accessibility, real estate prices, and attractiveness of different areas.

State of the art and operability of LUTI models. The first model that proved able to analyze the interactions between transport and urbanization was developed by Lowry. Since then theories and models have become increasingly complex over time. They can be classified according to different criteria. A first classification retraces the historic path of these theories and models. They can be associated with one or several of the approaches underlying all present theories: economic base theory and gravity models, Input/Output models and theory of urban rent, and micro-simulations. A second possibility consists in classifying the models according to their aims and means. Significant scientific progress has been made over the last thirty years. Nevertheless, modelling tools remain largely restricted to the academic world. Today, only seven models have at least had one recent application outside academia or are commercialized or potentially marketable, in spite of the important

[10] Congestion, cost and time spent for the transport, etc.
[11] Changes in modality choice.
[12] CO_2 emissions, air pollution, noise nuisance, etc.

needs expressed by the urban planning agencies: Cube Land, DELTA, MARS, OPUS/UrbanSim, PECAS, TRANUS and Pirandello.

To guide their choice of a modelling framework, users can rely on various criteria such as the strength of the theoretical framework, the quality and the diversity of the available documentation, the accessibility of the models (is the model freely available? is the code open source? is the software regularly updated and compatible with the recent operating systems?), the functionality and friendliness of user interfaces (existence of graphic user interface, possibility of interfacing with Geographic Information Systems), existence of technical assistance, volume and availability of the data required to implement the model, etc. For example, among the seven models mentioned above, only two are open source and mature enough to meet professional standards: TRANUS and UrbanSim [13]. These two models are very different but particularly representative of the main current philosophies and trends in this scientific domain. Their comparison is informative.

STEEP implication in LUTI modelling. As yet, very few local planning authorities make use of these strategic models, mostly because they are difficult to calibrate and validate. Systematic improvement on these two critical steps would clearly increase the level of confidence in their results; these limitations hinder their dissemination in local agencies. One of the major goals of STEEP is therefore to meet the need for better calibration and validation strategies and algorithms. This research agenda lies at the core of our project CITiES (ANR Modèles Numériques) that ended in 2017 with the PhD defense of Thomas Capelle . This work is being partly pursued in the QAMECS project.

As for LUTI modeling, we have been using the TRANUS model since the creation of our team. In this framework we work in close collaboration with AURG [14], the local urban planning agency of Grenoble (*Agence d'Urbanisme de la Région Grenobloise*) in order to better understand and to improve the relevance of these tools for such territorial agencies.

5. New Software and Platforms

5.1. USAT

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 [15].

NEWS OF THE YEAR: In 2019 we started a refactoring of this software, together with an overhaul of the associated web service USAT-WEB.

- Participants: Luciano Gervasoni, Serge Fenet, Peter Sturm and Roger Pissard-Gibollet
- Partner: LIRIS
- Contact: Peter Sturm
- URL: https://github.com/lgervasoni/urbansprawl

5.2. USAT WEB

Urban Sprawl Analysis Toolkit Web-service

KEYWORDS: Urban planning - Urban sprawl

[13] http://www.urbansim.org
[14] http://www.aurg.org/

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 [21].

NEWS OF THE YEAR: In 2019 we started a complete overhaul of this software, together with a factorization of the underlying computation core (USAT).

- Participants: Lucas Rezakhanlou, Peter Sturm, Luciano Gervasoni, Serge Fenet and Roger Pissard-Gibollet
- Contact: Peter Sturm
- Publication: USAT (Urban Sprawl Analysis Toolkit) : une plateforme web d'analyse de l'étalement urbain à partir de données massives ouvertes
- URL: https://gitlab.inria.fr/lrezakha/usat-web

5.3. LUM_OSM

Land Use Mix calculation from OpenStreepMap data

KEYWORD: Urban sprawl

FUNCTIONAL DESCRIPTION: The software uses Mapzen Metro Extracts to retrieve the OpenStreetMap data of a given region in the PostgreSQL format. Afterwards, a continuous representation of residential and activity land uses is created. Finally, a GIS output containing the degree of land use mixture is calculated by means of using the land uses maps. The implemented approach is documented in the paper "A framework for evaluating urban land use mix from crowd-sourcing data", http://hal.inria.fr/hal-01396792

- Participants: Luciano Gervasoni, Marti Bosch Padros, Peter Sturm, Serge Fenet and Roger Pissard-Gibollet
- Partners: EPFL - Ecole Polytechnique Fédérale de Lausanne - LIRIS
- Contact: Peter Sturm
- URL: http://github.com/martibosch/landusemix

5.4. Comptabilité Ecologique

FUNCTIONAL DESCRIPTION: Databases, database handling tools and data visualization tools (on the web-site). Databases include socio-economic and environmental datasets. Visualization tools include interactive piecharts, maps and Sankey diagrams.

- Participants: Jean-Yves Courtonne and Pierre-Yves Longaretti
- Contact: Jean-Yves Courtonne
- URL: http://www.eco-data.fr

5.5. REDEM

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 2019, the database underlying REDEM was updated with recent national emission trajectory information.

- Participants: Constantin Ilasca, Hélène Benveniste, Olivier Boucher, Patrick Criqui and Roger Pissard-Gibollet
- Partners: EDDEN - IPSL
- Contact: Emmanuel Prados
- URL: http://redem.gforge.inria.fr/

5.6. REDEM web

REDEM Web

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

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

- Participants: Constantin Ilasca, Emmanuel Prados, Hélène Benveniste, Nicolas Assouad, Olivier Boucher, Patrick Criqui and Roger Pissard-Gibollet
- Partners: UPMC - EDDEN
- Contact: Emmanuel Prados
- URL: http://redem.inria.fr/

6. New Results

6.1. Analysis of socio-ecological dimensions of human activities – A case study of Beaufort cheese production in the Maurienne Valley

The PhD thesis of Michela Bevione aims at analysing socio-ecological dimensions of human activities creating wealth by coupling quantitative-biophysical approaches and qualitative and socio-economic methodologies to assess territorial metabolism. By focusing on the interactions between flows and actors, the methodology we propose aims at providing a methodological framework for the understanding of a territory and its capability.

As a case study for this thesis, we chose to focus on the production of the AOC-labelled cheese Beaufort in the Maurienne Valley (Savoie department, Auvergne-Rhône-Alpes region, France). Indeed, agriculture play a structuring role for the economic and social dynamics of the valley, and the landscape construction induced by farming activities contributes to create favourable conditions to the development of the touristic sector. Beaufort represents the flagship product of the agricultural sector in the valley and most of farms are dedicated to milk production for the Beaufort industry.

In [7] we represent the circulation of material flows through flow maps, showing the movement of material and monetary resources and products, their direction, source and destination. We focus on the circulation of flows related to the Beaufort industry within the Maurienne Valley and between the valley and other territories. Through Sankey diagrams (a specific kind of flow maps, where the width of the arrows is proportional to the flow quantity) we present the dominant contributions to the overall material flows circulation. This kind of representation is appropriate to characterise the circulation of material flows, the allocation of environmental pressures throughout the Beaufort industry, as well as the monetary dimension and the added value associated to Beaufort production. Mapping the geographical origin of input resources and the destination of output products and incomes allows to evaluate actors' capacity to create wealth through the activation and mobilisation of local resources and/or their dependence on foreign inputs.

Furthermore, results include schematic representations of the relations between local, extra-territorial actors and the circulation of material, environmental and monetary flows. The influence of immaterial resources (informational flows and traditional savoir-faire) and local infrastructures on the circulation of flows, and vice versa, is illustrated. Finally, positive and negative retroactions induced by output products on input resources for Beaufort production are drawn, as well as the interactions with other sub-systems creating wealth in the valley.

6.2. Sensitivity analysis of World3

World3 is a computer tool created to simulate the interactions between the world population, industrial growth and food production within the limits of the planet. It aims to highlight the problems posed by indefinite material growth in a finite world. The first version of this tool was proposed in 1972 by MIT researchers for the first report to the Club of Rome [19]. This report was both highly successful and polemic. The main detractors of the model criticized it for being too approximate in the choice of the parameters and for beeing too simplistic. We started to work on revisiting some aspects of the scientific validation of this model, in a context where growth is widely debated in the scientific and civil community, through a new and more sophisticated sensitivity analysis of the model, compared to what is available in the literature [11].

6.3. Efficient computation of solution space and conflicts detection for linear systems

Our work on Material Flow Analysis (see e.g. the *AF Filières* project), involves the analysis of systems of linear inequalities, $l \leq Ax \leq u$. There are three different but complementary goals for the analysis: (i) given some known variables x_i, efficiently compute the solution space of unknown variables, (ii) if the set of constraints is infeasible, efficiently identify the conflicts, (iii) efficiently classify variables to determine whether they are redundant, just measured, determinable or non-determinable. A baseline implementation for these tasks was available in the team but proved to be too inefficient for larger problem sizes. Through the internship of Alexandre Borthomieu we worked on various improvements, on the algorithmic and implementation side (e.g. choice of programming language), that eventually led to a reduction of execution by three orders of magnitude, compared to the previous implementation.

6.4. Mapping ecosystem services bundles in a heterogeneous mountain region

2019 was the final year of production of the ESNET project (which officially ended in 2017). This and the following section describe our two most complex pieces of work in that project.

Recent institutional and policy frameworks prescribe the incorporation of ecosystem services (ES) into land use management and planning, favouring co-production of ES assessments by stakeholders, land planners and scientists. Incorporating ES into land management and planning requires models to map and analyze ES. Also, because ES do not vary independently, many operational issues ultimately relate to the mitigation of ES trade-offs, so that multiple ES and their interactions need to be considered. Using a highly accurate LULC (Land Use Land Cover) database for the Grenoble urban region (French Alps), we mapped twelve ES using a range of models of varied complexity [5]. A specific, fine-grained (less than 1 ha) LULC database at regional scale (4450 km^2) added great spatial precision in individual ES models, in spite of limits of the typological resolution for forests and semi-natural areas. We analysed ES bundles within three different socio-ecosystems and associated landscape types (periurban, rural and forest areas). Such type-specific bundles highlighted distinctive ES trade-offs and synergies for each landscape. Advanced approaches combining remote sensing, targeted field data collection and expert knowledge from scientists and stakeholders are expected to provide the significant progress that is now required to support the reduction of trade-offs and enhance synergies between management objectives.

6.5. Co-constructing future land-use scenarios for the Grenoble region, France

Physically and socially heterogeneous mountain landscapes support high biodiversity and multiple ecosystem services. But rapid landscape transformation from fast urbanisation and agricultural intensification around cities to abandonment and depopulation in higher and more remote districts, raises urgent environmental and planning issues. For anticipating their future in a highly uncertain socio-economic context, we engaged stakeholders of a dynamic urban region of the French Alps in an exemplary interactive participatory scenario planning (PSP) for co-creating salient, credible and legitimate scenarios. Stakeholders helped researchers adapt, downscale and spatialize four normative visions from the regional government, co-producing four storylines of trend versus break-away futures. Stakeholder input, combined with planning documents and analyses of recent dynamics, enabled parameterisation of high-resolution models of urban expansion, agriculture and forest dynamics. With similar storylines in spite of stakeholders insisting on different governance arrangements, both trend scenarios met current local and European planning objectives of containing urban expansion and limiting loss and fragmentation of agricultural land. Both break-away scenarios induced considerable conversion from agriculture to forest, but with highly distinctive patterns. Under a commonly investigated, deregulated liberal economic context, encroachment was random and patchy across valleys and mountains. A novel reinforced nature protection scenario affecting primarily mountain and hilly areas fostered deliberate consolidation of forested areas and connectivity. This transdisciplinary approach demonstrated the potential of combining downscaled normative scenarios with local, spatially-precise dynamics informed by stakeholders for local appropriation of topdown visions, and for supporting land planning and subsequent assessment of ecosystem service trade-offs. This work is described in [4].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

Contract with **ADEME** (French Environment and Energy Management Agency [15]), within a collaboration with FCBA [16], Arvalis [17], Terres Univia [18], and Terres Inovia [19]. 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 [20]), 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.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. 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

[15] https://www.ademe.fr/en
[16] https://www.fcba.fr
[17] https://www.arvalisinstitutduvegetal.fr/gis-@/view-607-arvstatiques.html
[18] http://www.terresunivia.fr
[19] https://www.terresinovia.fr
[20] https://en.auvergnerhonealpes-ee.fr

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.

8.2. National Initiatives

8.2.1. AF Filières : Analyse des Flux des Filières biomasse pour des stratégies régionales de bioéconomie

Project funded by ADEME
Duration: 2017-2019
Coordinator: Jean-Yves COURTONNE (Equipe STEEP, Inria) [Emmanuel Prados (STEEP/Inria) for Inria partner]
Other partners: Equipe STEEP, Inria, Grenoble Rhônalpénergie-Environnement (RAEE), Lyon Laboratoire d'Economie Forestière (LEF), INRA / AgroParisTech Nancy.
Keywords: Environmental assessment, Ecological accounting, Material Flow Analysis, Sustainable supply chains, Multicriteria analysis.
Abstract: Flow analyses of biomass supply chains for regional bioeconomy policies. The goals of the project are the following:

- Improve knowledge on the material flows of the forest-wood and agri-food supply chains in France at national and regional levels,
- Provide a holistic vision of the situation by associating environmental and socio-economic indicators to material flows,
- Provide a more precise assessments (quantitatively and qualitatively) in the case of the Auvergne-Rhône-Alpes region.

8.3. International Initiatives

8.3.1. Inria International Partners

8.3.1.1. Informal International Partners

University of Lausanne (UNIL), Department of Ecology and Evolution (Jérôme Gippet): development of the MoRIS model of propagation of invasive species.

8.3.2. Participation in Other International Programs

Pierre-Yves Longaretti is involved in TARA (Transition adaptation research alliance); he animated the theme *Operationalizing reflexive sustainability* at the TARA Workshop in Bogor, Indonesia, November 2019.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Selection

Jean-Yves Courtonne co-organized a special session entitled *Advances in understanding the physical structures of economies: Materials, energy, and the services they provide* at the 13th International Conference of the European Society for Ecological Economics, Turku, Finland, June 2019. https://esee2019turku.fi/specialsessions

9.1.1.1. Member of Conference Program Committees

- Peter Sturm, ORASIS 2019 (Journées francophones des jeunes chercheurs en vision par ordinateur), Saint-Dié-des-Vosges, France, https://orasis2019.sciencesconf.org
- Peter Sturm: Inria Science Days (Journées Scientifiques Inria), Lyon, France.

9.1.2. Invited Talks

- Jean-Yves Courtonne and Guillaume Mandil: *Durabilité forte : état des lieux et programme de recherche pour l'évaluation d'alternatives socio-techniques*, Colloque Soutenabilité des systèmes socio-techniques, Université Technologique de Troyes, France.
- Pierre-Yves Longaretti, *Global environmental collapse risks: is digital technology a problem or a solution?*, Keynote speech at LIG, Grenoble, France, June 2019.

9.1.3. Scientific Expertise

Jean-Yves Courtonne and Guillaume Mandil participate in the Steering Committe (COPIL) of the CODEC (Contrat d'Objectifs Déchets et Économie Circulaire) of Grenoble Alpes Métropole (Grenoble Metropolitan Area, https://www.lametro.fr/).

Team members intervened in training programs dedicated to IT professionals and teachers organized by EcoInfo [21], a French network dedicated to eco-responsible digital sciences and technologies:

- Guillaume Mandil provided a training session on Life Cycle Analysis for EcoInfo members, Grenoble, May 2019.
- Pierre-Yves Longaretti, Guillaume Mandil, and Peter Sturm gave lectures/training sessions at the week-long training seminar *Impact Environnemental du Numérique – Comprendre et Agir*, Autrans, France, September 2019.

9.1.4. Research Administration

- Emmanuel Prados and Guillaume Mandil are members of the Grenoble section of the *Labos 1.5* 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://labos1point5.org/en/home/
- Emmanuel Prados is member of the working group on sustainable development of the LJK lab, whose goal is to define and environmental charter and an environmental scientific policy for the lab.
- Peter Sturm is Deputy Scientific Director of Inria, in charge of the domain Perception–Cognition–Interaction.
- Peter Sturm co-founded and co-animated (with Céline Serrano) a national working group at Inria whose goal was to provide suggestions for the institute concerning environmental issues, in particular: (i) research to address the increasing environmental challenges (including directions of research and administrative aspects), (ii) how to reduce the ecological impact of the institute, and, more generally, (iii) ways of fostering responsible science ("sciences impliquées"). The working group produced a report [9] and several of its recommendations have already been taken up by Inria.

[21] https://ecoinfo.cnrs.fr

- 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 the CLDD of Inria Grenoble Rhône-Alpes (Local Sustainable Development Commission).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Jean-Yves Courtonne, Serge Fenet, Fausto Lo Feudo, Pierre-Yves Longaretti, Guillaume Mandil, Régis Perrier, Emmanuel Prados, Peter Sturm, and Françoise Berthoud (CNRS): *Les véritables enjeux environnementaux – compréhension, modélisations et outils quantitatifs*, 18 hours, graduate course, Université Grenoble Alpes, https://team.inria.fr/steep/seminars/cours-ed-2019/

Jean-Yves Courtonne: *Méthodes d'évaluation environnementale*, 1h30, Ensimag (Grenoble INP)

Jean-Yves Courtonne: *Méthodes d'évaluation environnementale*, 2h, Programme IDEX Green University, Université Grenoble Alpes

Pierre-Yves Longaretti: *Global changes, planetary limits and collapse risks*, 3h, Evry ENSIIE engineering school, May 2019.

Pierre-Yves Longaretti: *Global changes, planetary limits and collapse risks*, 3h, Grenoble ENSIMAG engineering school, October 2019.

Serge Fenet, Guillaume Mandil and Régis Perrier have regular teaching duties at the universities employing them.

9.2.2. 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: François-Rémi Mazy, *Vers une théorie et une implémentation algorithmique cohérentes des modèles statistiques de changement d'usage des sols*, started in October 2019, supervised by Pierre-Yves Longaretti

PhD in progress: Mathilde Jochaud du Plessix, *Robustesse et validité des modèles dynamiques de risques systémiques globaux*, supervised by Serge Fenet and Pierre-Yves Longaretti

9.2.3. Juries

- Pierre-Yves Longaretti was external expert of Grégoire Chambaz masters' thesis (UNIL, Lausanne): *The Evolutionary Dynamics of Societies Critical Synthesis of the Work of J.A. Tainter* et al. *on Sustainability, Collapse, Resilience and Energy Transitions.*
- Peter Sturm was reviewer of the Habilitation thesis of Gilles Simon (Université de Lorraine) and of the PhD thesis of Yilin Zhou (Université Paris-Est) and chaired the PhD thesis committee of Julien Salotti (Université de Lyon).

9.3. Popularization

9.3.1. Education

- Guillaume Mandil gave a half-day training course to a group of high school teachers (Lycée Mounier - CLEPT), July 2019.
- Peter Sturm gave a lecture on the environmental impact of ICT, during a training week of high school teachers of the Hauts-de-France Region, Lille, France, June 2019.

9.3.2. 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 must 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 2019 the YouTube channel has about 5,400 subscribers and reached a total of about 425,000 viewings.

The conference-debates of 2019:

- Olivier Vidal, Université Grenoble Alpes: Resources and energy at the global scale in the context of the energy transition (*Matières premières et énergie à l’échelle mondiale dans le contexte de la transition énergétique*)
- Grégoire Chambaz, Lausanne: How real is the risk of a blackout? (*Le risque de blackout est-il réel ?*)
- Christophe Bonneuil, CNRS and École des hautes études en sciences sociales: When the whites intended to preserve the planet – A history of geo-power, 1865-1914 (*Quand les blancs voulurent conserver la planète. Une histoire du géopouvoir, 1865-1914*)
- Peter Sturm, STEEP: Environmental challenges and what is blocking acting on them (*Enjeux environnementaux et blocages à l’action*)
- Sophie Wahnich, CNRS and Institut interdisciplinaire d’anthropologie du contemporain: Why was King Louis XVI destituted in 1792? Social imaginaries from 1770 to 1792 (*Pourquoi le roi Louis XVI a t-il été destitué en 1792 ? Imaginaires sociaux de 1770 à 1792*)
- Denis Dupré, STEEP: Collapses and finance (part I) – Is Finance a collapse pyromaniac? (*Effondrements et finance (partie I) – La Finance : pyromane des effondrements ?*)

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

9.3.3. Interventions

Guillaume Mandil participated in the preparation of an exposition at Cité des Sciences (Paris).

Team members gave the following general audience talks:

- Serge Fenet: Talk *Design et anthropocène : business as unusual – Une cartographie des risques par le prisme de la systémique* at the *Biennale Internationale du Design*, St-Étienne, France, May 2019.
- Serge Fenet: *Effondrements et anthropocène à la lumière de la dynamique des systèmes* at ESC Clermont-Ferrand, France, May 2019.

- Serge Fenet: *Technologies numériques et catastrophe environnementale : des liens complexes* at École Centrale de Lyon, for a general audience of master students.
- Pierre-Yves Longaretti: Seminar *Voluntary minimal consumption: stakes, obstacles, levers*. EcoInfo thematic school, November 2019.
- Pierre-Yves Longaretti: Seminar *Climate Change and strategic surprise*, Swiss military history and prospective center, December 2019.
- Pierre-Yves Longaretti: Round table discussion, *Will we all be farmers tomorrow? (Demain, tous paysans ?)*, Transition Towns biennial meeting, Grenoble, March 2019.
- Pierre-Yves Longaretti: Round table discussion, *Agriculture: global and local stakes (Agriculture : enjeux locaux et globaux)*, Forum citoyen alimentation & santé : La transition agro-alimentaire dans nos assiettes, Grenoble, November 2019.
- Emmanuel Prados: Institutional Conference *Veille techno à Polytech*, Grenoble, France, December 9-16, 2019. Organized by the MSTII Graduate School of Université Grenoble Alpes (Bernard Tourancheau).
- Emmanuel Prados: Institutional Conference organized by UniLaSalle (Hervé Leyrit), Beauvais, France, October 17, 2019.
- Emmanuel Prados: Conference at the back-to-school day of EPITA LYON (computer intelligence engineering school), Lyon, France, September 10, 2019. Organizer: Epita (Lamia Derrode).
- Emmanuel Prados: Conference on environmental transition for elected politicians of the Grésivaudan community of communes, open to the general public, Le Versoud, France, June 3rd, 2019. Organizer: Le Versoud City Hall (Claire Desmaris).
- Emmanuel Prados: General public conference, Crolles, France, June 22 , 2019. Organizer: Association *Ecocitoyens*.
- Emmanuel Prados: Conference at the *CitizenCampus* entitled *Transition, démocratie, effondrement : la quadrature du cercle ?*, Grenoble, France, March 29, 2019. Organizer: Université Grenoble Alpes. https://twitter.com/YannToma/status/1112094922499330049
- Emmanuel Prados: Conference/debate *Quelles transitions dans un contexte d'effondrement ?*, Palais des Sports de Grenoble, France, March 13, 2019. Organizer: Ville de Grenoble. http://villesentransition.grenoble.fr/events/quelles-transitions-dans-un-contexte-deffondrement/
- Emmanuel Prados: Conference within the ISN cycle, *Le numérique face aux enjeux environnementaux et sociétaux*, Grenoble, France, April 10, 2019. Organizer: Inria. https://www.canal-u.tv/video/inria/le_numerique_face_aux_enjeux_environnementaux_et_societaux.50079
- Emmanuel Prados: Invited conference at the Loria colloquium, *Le numérique face à la catastrophe environnementale et sociétale*, Nancy, France, February 8, 2019. Organizer: Loria (http://www.loria.fr/). https://www.loria.fr/fr/communication/colloquium-loria-exposes-et-videos/
- Peter Sturm made a "Tour de France" by bicycle, to raise awareness on environmental issues. During this trip (May 15 to July 4), he visited all Inria centers and gave a talk on *Environmental challenges and what is blocking acting on them* in ten locations (Sophia Antipolis, Montpellier, Bordeaux, Rennes, Saclay, Rocquencourt, Paris, Nancy, Lyon, Grenoble). His visits were accompanied by various events, including seminars by local researchers, meetings with sustainable development commissions, social gatherings, etc. This initiative is described at https://project.inria.fr/inriavelo/fr/, see also the daily blog https://www.polarsteps.com/PeterSturm3/1692663-inri-a-velo.

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] T. BIRDAL, B. BUSAM, N. NASSIR, S. ILIC, P. STURM. *Generic Primitive Detection in Point Clouds Using Novel Minimal Quadric Fits*, in "IEEE Transactions on Pattern Analysis and Machine Intelligence", 2019, pp. 1-14, https://arxiv.org/abs/1901.01255v1 , forthcoming [*DOI :* 10.1109/TPAMI.2019.2900309], https://hal.inria.fr/hal-02368932

[2] T. CAPELLE, P. STURM, A. VIDARD, B. MORTON. *Calibration of the Tranus Land Use Module: Optimisation-Based Algorithms, their Validation, and Parameter Selection by Statistical Model Selection*, in "Computers, Environment and Urban Systems", September 2019, vol. 77, pp. 101146:1-13 [*DOI :* 10.1016/J.COMPENVURBSYS.2017.04.009], https://hal.inria.fr/hal-01519654

[3] R. G. FRENCH, C. A. MCGHEE-FRENCH, P. NICHOLSON, M. M. HEDMAN, N. J. RAPPAPORT, E. A. MAROUF, P.-Y. LONGARETTI, J. HAHN. *Unusual One-Armed Density Waves in the Cassini Division of Saturn's Rings*, in "Icarus", 2019, pp. 1-59, forthcoming, https://hal.archives-ouvertes.fr/hal-02404628

[4] C. VANNIER, A. BIERRY, P.-Y. LONGARETTI, B. NETTIER, T. CORDONNIER, C. CHAUVIN, N. BERTRAND, F. QUETIER, R. LASSEUR, S. LAVOREL. *Co-constructing future land-use scenarios for the Grenoble region, France*, in "Landscape and Urban Planning", 2019, vol. 190, 103614 p. [*DOI :* 10.1016/J.LANDURBPLAN.2019.103614], https://hal.archives-ouvertes.fr/hal-02405231

[5] C. VANNIER, R. LASSEUR, E. CROUZAT, C. BYCZEK, V. LAFOND, T. CORDONNIER, P.-Y. LONGARETTI, S. LAVOREL. *Mapping ecosystem services bundles in a heterogeneous mountain region*, in "Ecosystems and People", February 2019, vol. 15, n^{o} 1, pp. 74-88 [*DOI :* 10.1080/26395916.2019.1570971], https://hal.archives-ouvertes.fr/hal-02404663

International Conferences with Proceedings

[6] S. PENG, P. STURM. *Calibration Wizard: A Guidance System for Camera Calibration Based on Modelling Geometric and Corner Uncertainty*, in "ICCV 2019 - International Conference on Computer Vision", Seoul, South Korea, 2019, pp. 1497-1505, https://arxiv.org/abs/1811.03264 , https://hal.inria.fr/hal-02368999

Conferences without Proceedings

[7] M. BEVIONE, N. BUCLET, J.-Y. COURTONNE, 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, https://hal.inria.fr/hal-02430879

[8] J.-Y. COURTONNE, J. ALAPETITE, V. WAWRZYIAK, M. BEVIONE. *The AF Filières project: application of PSUT frameworks for regional analyses of agriculture and forestry supply chains and footprints in France*, in "ESEE 2019 - 13th International Conference of the European Society for Ecological Economics", Turku, Finland, June 2019, pp. 1-4, https://hal.inria.fr/hal-02430898

Research Reports

[9] F. BERTHOUD, P. GUITTON, L. LEFÈVRE, S. QUINTON, A. ROUSSEAU, J. SAINTE-MARIE, C. SERRANO, J.-B. STEFANI, P. STURM, E. TANNIER. *Sciences, Environnements et Sociétés : Rapport long du groupe de travail MakeSEnS d'Inria*, Inria, October 2019, https://hal.inria.fr/hal-02340948

Other Publications

[10] A. BORTHOMIEU. *Efficient computation of solution space and conflicts detection for linear systems*, Université Grenoble Alpes, June 2019, Mémoire M1 sous la forme d'article, https://hal.inria.fr/hal-02433237

[11] M. JOCHAUD DU PLESSIX. *Analyse du modèle World3 : sensibilité, dynamique, et pistes d'évolution*, Insa Lyon, September 2019, https://hal.inria.fr/hal-02434683

[12] F.-R. MAZY. *Conceptually correct and algorithmically efficient pruning and allocation procedures in statistical LUCC modelling*, Université Grenoble Alpes, September 2019, https://hal.inria.fr/hal-02302133

References in notes

[13] U. BARDI. *The Limits to Growth Revisited*, Springer Verlag, 2011

[14] E. BOVARI, G. GIRAUD, F. MC ISAAC. *Coping With Collapse: A Stock-Flow Consistent Monetary Macrodynamics of Global Warming*, in "Ecological Economics", 2018, vol. 147, pp. 383-398

[15] L. GERVASONI, M. BOSCH, S. FENET, P. STURM. *LUM-OSM : une plateforme pour l'évaluation de la mixité urbaine à partir de données participatives*, in "Atelier Gestion et Analyse des données Spatiales et Temporelles", Grenoble, France, Cyril De Runz and Eric Kergosien and Thomas Guyet and Christian Sallaberry, January 2017, https://hal.inria.fr/hal-01548341

[16] I. GOLDIN, M. MARIATHASAN. *The Butterfly Defect: How Globalization Creates Systemic Risks, and What to Do about It*, Princeton University Press, 2014

[17] D. KOROWICZ. *Trade-off: Financial System Supply-Chain Cross Contagion — a Study in Global Systemic Collapse*, 2012, http://www.feasta.org/wp-content/uploads/2012/10/Trade_Off_Korowicz.pdf

[18] D. MEADOWS, W. BEHRENS III, D. MEADOWS, R. NAILL, J. RANDERS, E. ZAHN. *Dynamics of Growth in a Finite World*, Wright-Allen Press, 1974

[19] D. MEADOWS, D. MEADOWS, J. RANDERS, W. W. BEHRENS. *The Limits to Growth*, Universe Books, 1972

[20] D. MEADOWS, J. RANDERS, D. MEADOWS. *The Limits to growth, The 30-Year Update*, Chelsea Green Publishing, 2004

[21] L. REZAKHANLOU, S. FENET, L. GERVASONI, P. STURM. *USAT (Urban Sprawl Analysis Toolkit) : une plateforme web d'analyse de l'étalement urbain à partir de données massives ouvertes*, in "Atelier Démo de la conférence SAGEO (Spatial Analysis and Geomatics)", Rouen, France, November 2017, https://hal.inria.fr/hal-01610738

[22] G. TURNER. *A Comparison of The Limits to Growth with 30 Years of Reality*, in "Global Env. Change", 2008, vol. 18, pp. 397-411

[23] G. TURNER. *Is Global Collapse Imminent?, MSSI Research Paper No. 4. Melbourne Sustainable Society Institute, University of Melbourne*, Melbourne Sustainable Society Institute, University of Melbourne, 2014