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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**

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Project-Team STEEP

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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 (LJK¹).

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.

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.

¹ <http://ljk.imag.fr/>

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, *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 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.

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.

²<http://www.gmo-free-regions.org>

³<http://www.necstour.eu>

⁴Gross Domestic Product (GDP) is defined as an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production.

3. 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.

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.

⁵<http://www.urbansim.org>

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). 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 devising metamodels (or, surrogate models) that approximate an original model and may be simulated, calibrated, or analyzed more efficiently. As for detecting

⁶<http://www.csr.ufmg.br/dinamica/>

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.

4. Application Domains

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. Let us 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.

STEEL 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 ⁷, on user behavior ⁸, or on the environment ⁹. 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 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 ¹⁰. These two models are very different but particularly representative of the main current philosophies and trends in this scientific domain. Their comparison is informative.

STEPP 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.

⁷ Congestion, cost and time spent for the transport, etc.

⁸ Changes in modality choice.

⁹ CO₂ emissions, air pollution, noise nuisance, etc.

¹⁰ <http://www.urbansim.org>

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 ¹¹, 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. Highlights of the Year

5.1. Highlights of the Year

The STEEP research team has initiated in 2016 a series of conferences-debates entitled “Understanding & Acting” (« Comprendre et agir ») that examines sustainability 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. The presentations are captured on video and then made directly accessible on the YouTube Channel “Comprendre et Agir”. At the end of 2017 the YouTube channel reached almost **45,000 views with a rate of integral viewings remaining at above 25%. This rate is quite important since the YouTube videos of the conferences last between 35 and 45 minutes.**

6. New Software and Platforms

6.1. Software tools for the TRANUS LUTI Model

KEYWORDS: Urban planning - Transport model - LUTI

FUNCTIONAL DESCRIPTION: This year, we have consolidated and extended our software tools for the TRANUS LUTI model, thanks to support by Inria allowing to hire an engineer for one year Emna Jribi (ADT TRACAV project). Various tasks have been accomplished, concerning three types of functionality, these are as follows. First, calibration of TRANUS. The software implementation of our methods for calibrating the TRANUS land-use component has been cleaned up. It has been encapsulated such as to be seamlessly integrated within the TRANUS workflow (consisting of a sequence of executables, exchanging data through binary and other files). Second, graphical user interfaces to facilitate the repeated execution of TRANUS executables, for generating reports on results or for the exploration of the space of some critical model parameters. Third, we have continued to work on the embedding of TRANUS within the open source QGIS platform (a widely used Geographic Information System).

- Participants: Emna Jribi, Thomas Capelle and Peter Sturm
- Contact: Peter Sturm
- URL: <https://gitlab.inria.fr/tranus>

6.2. 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 [14].

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

¹¹<http://www.aurg.org/>

6.3. USAT WEB

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 [15].

- Participants: Lucas Rezakhanlou, Peter Sturm, Luciano Gervasoni and Serge Fenet
- 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>

6.4. InterfacesTRANUS

FUNCTIONAL DESCRIPTION: This software contains two interfaces dedicated to facilitating the usage of the TRANUS integrated land use and transport model+software. The first interface is dedicated to enabling the execution of the TRANUS binary programs without the need to use the console or the TRANUS GUI. The second interface provides an aid for calibrating a TRANUS model, by interactively exploring ranges of different parameters of a TRANUS model and visualising model outputs across these ranges.

- Participants: Julien Armand, Peter Sturm and Thomas Capelle
- Contact: Peter Sturm
- URL: https://gitlab.inria.fr/tranus/TRANUS_Interfaces

6.5. LUM_OSM

Land Use Mix calculation from OpenStreepMap data

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 and Serge Fenet
- Partners: EPFL - Ecole Polytechnique Fédérale de Lausanne - LIRIS
- Contact: Peter Sturm
- URL: <http://github.com/martibosch/landusemix>

6.6. QGIS_Tranus_Reports

FUNCTIONAL DESCRIPTION: This software allows to graphically visualise data output by the TRANUS LUTI model (and possibly, of any other data of the same structure). In particular, this concerns any data items defined per zone of a modelled territory (productions, indicators, etc.). The software is designed as a plugin for the geographical information system platform QGIS and can be run interactively as well as by the command line or by a call from within another software. The interactive mode (within QGIS) allows the user to define graphical outputs to be generated from TRANUS output files (type of graphs to be generated – 2D or 3D – color coding to be used, choice of data to be displayed, etc.). Visualisation of data is done in the form of 2D graphs or 3D models defined using java-script.

- Participants: Fausto Lo Feudo, Huu Phuoc Nguyen, Patricio Inzaghi, Peter Sturm and Thomas Capelle
- Contact: Peter Sturm
- URL: https://gitlab.inria.fr/tranus/QGIS_Tranus_Reports

6.7. Comptabilité Ecologique

FUNCTIONAL DESCRIPTION: Databases, database handling tools and data visualization tools (on the website). 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>

7. New Results

7.1. Calculating spatial urban sprawl indices using open data

Urban sprawl has been related to numerous negative environmental and socioeconomic impacts. Meanwhile, urban areas have been growing at alarming rates, urging for assessing sprawl towards sustainable development. However, sprawl is an elusive term and different approaches to measure it have lead to heterogeneous results. Moreover, most studies rely on private/commercial data-sets and their software is rarely made public, impeding research reproducibility and comparability. Furthermore, many works give as result a unique value for a region of analysis, dismissing local spatial diversity that is vital for urban planners and policy makers.

Based on our last year's initial work [19], we have developed an extended open source framework for assessing urban sprawl using open data. Locations of residential and activity units are used to measure mixed use development and built-up dispersion, whereas the street network is used to measure accessibility between different land uses. Sprawl patterns are identified, and the resulting spatial information allows focusing on particular neighborhoods for a fine-grained analysis, as well as visualizing each sprawl dimension separately.

This work has been published in [10], [14], [15] and the associated implementation is available as open source software (see previous section).

7.2. A method for downscaling open population data

To extend our ongoing work on urban sprawl indicators (see above), we have developed a method to perform disaggregated population estimations at building level using open data. Our goal is to estimate the number of people living at the fine level of individual households by using open urban data and coarse-scaled population data. First, a fine scale description of residential land use per building is built using OpenStreetMap. Then, using coarse-scale gridded population data, we perform the down-scaling for each household given their containing area for residential usage. We rely solely on open data in order to ensure replicability, and to be able to apply our method to any city in the world, as long as sufficient data exists. The evaluation is carried out using fine-grained census block data for cities in France as ground-truth.

This work is published in [11] and the associated software implementation is made available as open source code at <https://github.com/lgervasoni/urbansprawl>.

7.3. Ecological accounting

The most important result obtained on this front bears on the quantification of the errors associated with the national road freight transport database (SITRAM). This database is informed year by year through a dedicated sampling campaign, but the errors associated with the various types of material goods transported have never been quantified. This was achieved by our team through the use of appropriate error estimators. This result is eagerly awaited by a number of scientific teams and public territorial agencies. Furthermore, the methodology that we have developed can easily be transposed to other countries. This result constitutes an important piece in the overall effort that the team has devoted to the question of the quantification of uncertainties in material flow analyses. This work is in the press in the leading journal in this field, the *Journal of Industrial Ecology*.

7.4. A computer framework for measuring urban land-use mix

The number of people living in cities has been increasing considerably since 1950, from 746 million to 3.9 billion in 2014, and more than 66% of the world's population are projected to live in urban areas by 2050. As this continuing population growth and urbanization are projected to add 2.5 billion people to the world's urban population in 30 years, this situation brings new challenges on how to conceive cities that host such amounts of population in a sustainable way. This sustainability question should address several aspects, ranging from economical to social and environmental matters among others. In this work, we focus on the formalization of a measure of mixed use development or land use mix in a city, i.e. how the structure of the city can help to provide a car-free sustainable living. Such type of land use mix has been largely proven to contain beneficial outcomes in terms of sustainability and to positively contribute to societal outcome, health, and public transportation among others. We developed a framework to compute mixed uses development index. A main characteristic of our approach is to use only crowd-sourcing data (from OpenStreetMap) to extract the geo-localized land uses. Due to the universality of this data source, we are able to process any geographical area in the world, as long as sufficient data are available in OSM. A Kernel Density Estimation is performed for each of the land uses, outputting the spatial distribution of the different land uses. Based on this representation, a measure of land use mix is then calculated using the Entropy Index. The resulting GIS output shows enriched information for urban planners, supporting and aiding the decision-making procedure.

The framework, still in the phase of validation, was applied on the cities of London and Grenoble [19]. Future work includes integrating the LUM output for measuring the urban sprawl phenomenon and performing numerical interpretations of desirable mixed use values. We will also study the potential integration to transportation models, where land use mix correlation with the activities and residential uses can help to improve demand estimation. In addition, further investigation can be done by means of analyzing in detail the different types of activities. Finally, the estimation of LUM can be refined by taking into account, besides their location, the accessibility between different land uses, which is partly conditioned by the transportation infrastructure.

7.5. Calibration and sensitivity analysis for LUTI models

This year, we have consolidated our previous works on calibration of LUTI models, in particular of the Tranus model. The developed approaches are currently applied to instantiate a complete Tranus model for the Grenoble catchment area, in collaboration with AURG (Urban Planning Agency of the Grenoble area) and Brian Morton (U North Carolina) ; see [12], [13].

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. *QAMECS : ATMOSPHERIC POLLUTION: Characterization of novel exposure markers, of biological, health, economic and societal impacts and evaluation of public policies*

Project funded by ADEME and Grenoble metropolis

Duration: 2016 – 2019

Project coordinator : Remy Slama - INSERM. 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 (PM_{2.5}) 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.

8.2.2. *ESNET : Futures of ecosystem services networks for the Grenoble region*

Project funded by FRB (Fondation pour la Recherche sur la Biodiversité)

Program: "Modeling and Scenarios of Biodiversity" flagship program, Fondation pour la Recherche sur la Biodiversité (FRB). This project is funded by ONEMA (*Office National de l'Eau et des Milieux Aquatiques*).

Duration: 2013 – 2017

Coordinator: Sandra Lavorel (LECA)

Other partners: EDDEN (UPMF/CNRS), IRSTEA Grenoble (formerly CEMAGREF), PACTE (UJF/CNRS), ERIC (Lyon 2/CNRS)

Abstract: This project explores alternative futures of ecosystem services under combined scenarios of land-use and climate change for the Grenoble urban area in the French Alps. In this project, STEEP works in particular on the modeling of the land use and land cover changes, and to a smaller extent on the interaction of these changes with some specific services.

8.2.3. CITiES: Calibrage et validation de modèles Transport - usage des Sols

Project funded by ANR

Program: “Modèles Numériques” 2012, ANR

Duration: 2013 – 2017

Coordinator: Emmanuel Prados (STEEP)

Other partners: LET, IDDRI, IRTES-SET (“Systemes and Transports” lab of Univ. of Tech. of Belfort-Montbéliard), IFSTTAR-DEST Paris (formerly INRETS), LVMT (“Laboratoire Ville Mobilité Transport”, Marne la Vallée), VINCI (Pirandello Ingenierie, Paris), IAU Île-De-France (Urban Agency of Paris), AURG (Urban Agency of Grenoble), MOISE (Inria project-team)

Abstract: Calibration and validation of transport and land use models.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

- Denis Dupré, Pierre-Yves Longaretti and Emmanuel Prados are the Scientific Chair of the series of conferences entitled “Understanding and Acting”; see section 9.3.1.

9.1.2. Scientific Events Selection

9.1.2.1. Member of the Conference Program Committees

- P. Sturm was member of the program committee of the 2017 Inria Science Days

9.1.3. Journal

9.1.3.1. Reviewer - Reviewing Activities

- P. Sturm: Journal of Sensors

9.1.4. Scientific Expertise

- P. Sturm: Expert for the European Eureka/Eurostars program and for the regional ARC6 program.
- Since 2015 Emmanuel Prados is member of the GICN (“Groupe Interdisciplinaire sur les Contributions Nationales”), the group of scientific experts mandated by french ministry of Sustainable Development to prepare the **climate change conference COP21** in December. This group is still active and always advises French political actors in climate negotiations.

9.1.5. Research Administration

- P. Sturm is, since 2015, Deputy Scientific Director of Inria, in charge of the domain Perception–Cognition–Interaction
- E. Prados and P. Sturm organized the Inria – FING partnership. The FING (Fondation Internet Nouvelle Génération) is a think tank working on socio-economic changes inspired by technology and its uses. In 2017, they organized three workshops in the framework of the project “Transition²” [<http://www.transitions2.net/>].
- E. Prados was in charge of the working group “Digital tools for the progress of society” for the Strategic Plan of Inria, 2017. His work resulted in the writing of the Scientific Challenges entitled “Digital world, society, and complexity”.

- Denis Dupré, Pierre-Yves Longaretti and Emmanuel Prados are the coordinator of the working group “Democracy and digital technology”. Created in 2017, this working group is a permanent one that gathers various researchers and actors located at the Grenoble pole. This group leads a global reflection on the digital world and the democratic issues. It aims to bring out lines of action of research in the medium term.
<https://project.inria.fr/democratieetnumerique/>

9.2. Teaching - Supervision - Juries

9.2.1. Supervision

PhD : Thomas Capelle, *Development of optimization methods for land-use and transportation models*, University Grenoble Alpes, February 15rd, 2017, Peter Sturm (supervisor) and Athur Vidard (co-supervisor).

PhD in progress : Michela Bevione, *Socio-ecological transition, wealth creation and territorial metabolism: the case of Maurienne Valley*, October 2016, Pierre-Yves Longaretti (co-supervisor) and Nicolas Buclet (supervisor). Phd thesis in collaboration with the PACTE Laboratory. This interdisciplinary research on territorial ecology aims at bridging the gap between quantitative modeling and socio-economic and qualitative approaches to better understand the interactions between human society and the environment.

PhD in progress : Luciano Gervasoni, *Modeling the dynamics of urban sprawl*, October 2015, Peter Sturm (supervisor) and Serge Fenet (co-supervisor).

9.2.2. Juries

- P. Sturm was member of the PhD committees of René Emmanuel Datondji (Université Rouen, president), Andrey V. Kudryavtsev (Université Franche-Comté reviewer), Abdelkader Bellarbi (Université Evry Val d'Essonne, reviewer), and Yohan Salaün (Université de Paris-Est, reviewer).
- E. Prados was member of the PhD thesis jury (as examiner) of Rémy Lasseur ; University of Grenoble Alpes - UGA (July 10th, 2017). Title : “Multi-scale mapping of ecosystem services: characterizing spatial associations and insights from remote sensing”

9.3. Popularization

9.3.1. Conferences “Understanding and Acting” :

Saving Civilization is not a spectator sport
Lester Brown

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 2017 the YouTube channel reached almost 45,000 views with a rate of integral viewings remaining at above 25%.

Examples of conferences given in 2016-2017:

- “Why and how to recognize money as a common good?” by Jean-Michel Servet, Graduate institute of international and development studies (IHEID) at Genève.
- “What alternative to the crisis of representation?” by Loic Blondiaux, University of Paris I Panthéon-Sorbonne.
- “Reinventing agriculture and food in the 21st century?” by Gilles Billen, CNRS.
- “Can the commons movement re-activate democracy?” by Christian Laval, University of Paris Ouest Nanterre La Défense.
- “Limiting climate change: Why do we not do it?” by Denis Dupré, University of Grenoble Alpes.
- “Understanding society collapses. What future for ours?” by Emmanuel Prados, Inria.
- “Environment, economy, collapse: squaring the circle?” by Pierre-Yves Longaretti, CNRS.

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

9.3.2. Other popularization activities :

- Emmanuel Prados gave a conference entitled “Understanding society collapses. What future for ours?” at the series of conferences “Understanding and Acting” (Grenoble, France, 9th of February, 2017). The video of the conference has been posted on the video-sharing website, YouTube. The conferences received around 30 000 YouTube views in 10 months.
<https://www.youtube.com/watch?v=1dgjIeR5DBY>
- Pierre-Yves Longaretti gave a conference entitled “Environment, economy, collapse: squaring the circle?” at the series of conferences “Understanding and Acting” (Grenoble, France, 3rd of March, 2017). The video of the conference available on YouTube. The conferences received around 1700 views in 9 months.
<https://www.youtube.com/watch?v=0T8SP5jb3aI>
- Emmanuel Prados participated in the round table “How to manage territories with the help of numerical models” held for the celebrated days for the 50th birthday of Inria (Paris, France, November 7th, 2017).
- Denis Dupré gave a conference entitled “Can ethical finance prevent from our civilization collapse ?” at the department of banking and finance of the University of Zurich (Zurich, Switzerland, the 29th of September 2017). The video of the conference available on YouTube. <https://www.youtube.com/watch?v=JhFiksORbMU>
- Denis Dupré gave a conference entitled “How finance can help to manage vital goods in the coming collapse?” at the “Change Finance Forum” organized by Financewatch (Brussels, Belgium, 5th december 2017). The video of the conference available on YouTube. <https://www.youtube.com/watch?v=3RyJTn0a-ZA>
- Denis Dupré gave an interview at France Info, December 11, 2017. France Info is the radio network operated by the French public service radio broadcaster Radio France which provides continuous live news and information. Interview available online :
<https://team.inria.fr/steep/denis-dupre-dec-11-2017/>

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