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Activity Report 2013

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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Team STEEP

Keywords: Modeling, Simulation, Environment, Socio-economic Models, Territorial Scales, Decision Aid

Creation of the Team: 2010 January 01.

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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 currently an "équipe centre" of Inria Grenoble - Rhône-Alpes and is also affiliated with the Jean Kuntzmann laboratory (LJK [1]). The process of creating an EPI (équipe projet Inria) is underway and planned to be completed in 2014.

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

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?*.

This theme is new at Inria, but also for the researchers of STEEP who previously worked in other fields. Elise Arnaud, Emmanuel Prados and Peter Sturm worked on computer vision and Pierre-Yves Longaretti is a physicist. Some STEEP staff are still in the process of their own thematic transition and a significant part of their activity is not or only briefly mentioned in this document.

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

Sustainable development is often formulated in terms of a required balance between the environmental, economic and social dimensions, but public policies addressing sustainability are in practice dominantly oriented towards environmental issues in Western countries. However, the numerous and interrelated pressures exerted by human activity on the environment make the identification of sustainable development pathways arduous in a context of complex and sometimes conflicting stakeholders and socio-ecological interactions.

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 process, with more than half the human population living in cities, an ever-increasing trend. 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 peri-urban growth. This phenomenon has both social and environmental consequences, like an increased vulnerability of some population categories or a fragmentation of ecological habitat. Controlling urban sprawl is therefore a key sustainability issue.

The issues just described require a panel of policy measures at all institutional levels, as they illustrate the existence of both local-local and local-global feedback loops. The regional (sub-national) and more local levels are of particular importance for the transition to sustainability, especially in a “think global/act local” approach that is up to now mostly oriented towards local climate and territorial energy plans. In this context, more 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.

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), 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 [2], 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. A second LUTI model that will be considered in the near future, within the CITiES project, is UrbanSim [3]. Whereas TRANUS aggregates over e.g. entire population or housing categories, UrbanSim takes a micro-simulation approach, modeling and simulating choices made at the level of individual households, businesses, and jobs, for instance, and it operates on a finer geographic scale than TRANUS.

On the other hand, the scientific domains related to eco-system 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 and material flow analysis only proposes statistical models based on more or less simple data correlations. The eco-system 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 will work in particular on a land use/ land cover change (LUCC) modelling environments (LCM from Clark labs [4], and Dinamica[5]) which belongs to the category of spatially explicit statitistical models.

[2] http://www.modelistica.com/english
[3] http://www.urbansim.org
[4] http://www.clarklabs.org/products/Land-Change-Modeler-Overview.cfm
[5] http://www.csr.ufmg.br/dinamica/

In the following, our three main research axes are described.

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 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. All these uses of SA will be considered in our research.

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 will have to be circumvented e.g. difficulties arising from dependencies of input variables, variables that obey a spatial organization, or switch inputs. We will 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 will 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 will work towards using sensitivity indices based on functional analysis of variance, which will allow us to compare the influence of various inputs on the indicators. For example it will allow the comparison of the influences of transportation and land use policies on several indicators.

3.4. Modeling of socio-economic and environmental interactions

Considering the assessment of socio-economic impacts on the environment and ecosystem service analysis, the problems encountered here are intrinsically interdisciplinary: they draw on social sciences, ecology or Earth sciences. The modeling of the considered phenomena must take into account many factors of different nature which interact *via* various 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. The spatial processes involve proximity relationships and neighborhoods, like for example, between two adjacent parcels of land. 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. The multi-scale approaches can also be justified by the lack of data at the relevant scales. This is for example the case for the material flow analysis at local scales for which complex data disaggregations are required.

At this stage, it is crucial to understand that the scientific fields considered here are far from being mature. For example, the very notions of ecosystem services or local ecological accounting are quite recent and at best partially documented, but advances in those fields are essential, and will be required to identify transition paths to sustainability. Nowadays, the analyses are only qualitative or statistic. The phenomena are little understood. Our goal here is then to do upstream research. It is to anticipate and to help the development of modeling tools that will be used tomorrow in these fields.

Developing 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; cellular automata, multi-agent models, system dynamics, or large systems of equations describing equilibrium models? 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? How to

get models which automatically adapt to the granularity of the data and which are always numerically stable? 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?
Providing satisfying answers to these questions is a long term goal for STEEP.

4. Application Domains

4.1. Urban economy and land use and transport modeling

Modern urban regions are highly complex entities. The understanding of the phenomena underlying urban sprawl and peri-urbanization is a key element to control the dynamics structuring urban space. Clearly, urban transport systems are intricately linked to urban structure and the distribution of activities, i.e., to land use. Urbanization generally implies an increase in travel demand. Cities have traditionally met this additional demand by expanding the 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.

Several models have been developed in the field of urban economics to understand the complex relationship between transportation and land use and to facilitate the urban planning process. They enable the simulation of public policies and the quantification of indicators describing the evolution of urban structure. Key factors such as transport congestion, energy consumption, CO_2 emissions etc., can be evaluated or estimated, and different urban development scenarios can be tested in a quantitative manner.

Yet, very few local authorities in charge of planning issues make use of these strategic models, mostly because they are difficult to calibrate and validate, two critical steps where systematic improvement would increase the level of confidence in the obtained results. These limitations prevent dissemination in local agencies. One goal of STEEP is therefore to meet the need of better calibration and validation strategies and algorithms. This research is the core of our projects CITiES (ANR Modèles Numériques) and TRACER (Ecos Nord Venezuela).

4.2. Ecological accounting and material flow analysis

One of the major issues in the assessment of the long-term sustainability of urban areas is related to the concept of “imported sustainability”. Indeed, any city brings from the outside most of its material and energy resources, and rejects to the outside the waste produced by its 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.

In order to produce such an assessment for a given territory or urban area, one must first establish different types of ecological accounting: one must identify and quantify the different types of material and energy uses on the one hand, and the different types of impact associated to these uses. Two approaches are being investigated. The bottom-up approach relies on Material Flow Analysis (MFA) and Life Cycle Assessment (LCA). One of the major challenges here is to obtain reliable MFA data at the region and *département* scales, either directly, or through appropriate disaggregation techniques. The top-down approach is based on Environmentally-Extended Input-Ouput Analysis (EE-IOA). This technique which originated from economic sciences has been widely used in recent years in the fiels of ecological economics and industrial ecology. In both cases, the methods aim at tracking environmental flows from the producer to the consumer making them relevant tools for decision-making regarding local modes of production and consumption.

STEEP has started a research program on this theme with three major aims in mind: 1) Creating a comprehensive database enabling such analyses; 2) Developing methodology and models resolving scaling issues, and developing algorithms allowing to rigorously and automatically obtain the adequate assessments; 3) Providing a synthetic analysis of environmental impacts associated to the major material flows, at various geographic levels (employment catchment area, *département* and *région*, for France). This research is currently done within an industrial grant with ARTELIA.

4.3. Eco-system services

Long-term sustainability is closely related to the underlying ecosystems, on various fronts: production of renewable resources (either energy or biomass), waste and pollutant resorption, local and global climate regulations etc. These various functions constitute the "ecosystem services" provided to society by our natural environment.

The reduction of the adverse impacts of urban areas on the environment is linked not only to limiting urban sprawl and making more efficient use of the available resources, but also to developing a better grasp of the interrelations between urban/peri-urban areas and their agricultural and semi-natural surroundings. In particular, reducing distant impacts while making a better use of local resources is a major challenge for the coming decades.

In this context, the STEEP team is involved in the ESNET project, bearing on the characterization of local Ecosystem Services Networks, piloted by LECA (*Laboratoire d'Ecologie Alpine*), and in collaboration with a number of other research laboratories (most notably, IRSTEA Grenoble) and 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. The contribution of the STEEP team is centered on the Land Use/Land Cover Change (LUCC) model that will be one of the major building blocks of the whole model.

5. Software and Platforms

5.1. TEOS: Tranus Exploration and Optimization Software

Participants: Anthony Tschirhard, Mathieu Vadon, Elise Arnaud, Emmanuel Prados.

The TEOS software offers a set of tools to help the calibration of the land use and transport integrated model TRANUS. It uses some exploration and optimization procedures of the relevant parameters.

5.2. REDEM: REDuction Of GHG EMission software

Participant: Emmanuel Prados.

REDEM software (REDuction of EMissions) is a tool designed for the benchmarking of national GHG emission reduction trajectories. We have developed REDEM in collaboration with EDDEN Laboratory (Patrick Criqui and Constantin Ilasca). 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. We envisage to distribute this software as an open source software.

5.3. Wassily

Participants: Julien Alapetite, Jean-Yves Courtonne, Lara Antonela Colombo, Pablo Virgolini.

In collaboration with the association "Groupe de Réflexion sur les Empreintes Ecologiques Locales" (eco-data.fr), STEEP contributes to the development of Wassily (in tribute to Wassily Leontief who first designed the relevant concepts), to perform input-output analyses applied to environmental issues (see section 4.2). The purpose of this software is to automatize most of the work of standard input-output analysis and to visualize the results in a user-friendly way in order to efficiently address the related key environmental questions.

The software is structured in three different modules:

- the database module stores all the input-output data coming from Eurostat, OCDE, Insee or other sources.
- the computation module performs the input-output calculations
- the visualization module displays the results in a synthetic manner.

The database module is based on the SQlite format and makes use of SQL to manipulate the various tables involved in the process. The goal of this module is to provide a normalized data interface for the computation module, from various types of input-output data which are often stored as Excel sheet on web sites.
The computation module is based on QT and C++ and deals mostly with matrix manipulation.
The visualization module is based on a JavaScript library called D3 and allows the user to visualize the results in a number of different ways, such as bar charts, pie charts, sankey diagrams to name a few. The integration between the C++ and JavaScript pieces of code is performed with QTScript.

6. New Results

6.1. Data Mining for Material Flow Analysis: Application in the Territorial Breakdown of French Regions

One of the major issues for assessment of the long-term sustainability of urban areas is related to the concept of “imported sustainability”. In order to produce such an assessment for a given territory, one must first identify and quantify the types of materials used, and the impacts associated to these uses. Material Flow Analysis (MFA) is directly related to how the material circulates and how it is transformed within a territory. In most cases this analysis is performed at national and regional levels, where the statistical data is available. The challenge is to establish such an analysis at smaller scales, e.g. in the case of France, at the department or city level.

We have explored the possibility of applying data analysis at the regional level by generating a mathematical model that can fit well the data at regional scale and estimate well the departmental one. The downscaling procedure relies on the assumption that the obtained model at level ‘n’ (for example region) will be also true at level ‘n+1’ (for example department), such that it could properly estimate the unknown data based on a set of chosen drivers (socio-economic data). We have designed and implemented techniques based on parameter optimization and model selection as well as robust estimation, in order to estimate the best drivers for a given set of territories, i.e. the socio-economic data (e.g. employees per type of manufacturing industry, population data, etc.) that best correlate with the production of various types of agricultural or other products [19].

6.2. Calculating indices for urban sprawl

Urban sprawl is a complex concept, that is generally associated with auto-oriented, low-density development. It is the subject of a wide range of research efforts, aiming at understanding and characterizing the underlying driving factors. We have followed up on an effort by Burchfield et al. who proposed a simple measure for urban sprawl, a so-called sprawl index. We proposed several variants of this index with the aim of achieving richer and/or more flexible characterizations of urban sprawl [16]. We also proposed ways of determining metropolitan areas that have similar patterns of urban sprawl, using clustering techniques.

6.3. Computing environmental accounts from the consumer's viewpoint using Input Output Analysis

The Russian-American economist Wassily Leontief introduced Input-Output Analysis (IOA) in the 30's and was awarded the Nobel prize in economy in 1973 for this contribution. IOA is a macro-economic tool which investigates the links and retroactions between the sectors of an economy. It makes it possible to allocate production factors (labor, capital etc.) and environmental externalities of production processes (depletion on resources, emission of pollutants etc.) to final consumption. Our first task was to reproduce the results from various studies on the carbon footprint of France. We couldn't reproduce the results from *Analyse des impacts environnementaux de la consommation des ménages et des marges de manœuvre pour réduire ces impacts* (Ademe, 2012). We underlined a mistake in the mathematical formulas presented in the annex of the paper but couldn't concur it was indeed the source of discrepancy because we were not granted access to the raw data of the study. Our results are however in line with the papers originating from the statistical service of the ministry of ecology (SOeS, J-L Pasquier).

Because working on excel sheets, although widespread in a large number of agencies, proves very inefficient, we started to work on the development of a software called Wassily (see "new results" section) that would automatize the critical calculations. We prepared databases on input-output tables and air emissions of several European countries based on Eurostat data and started to work on the architecture of the software with Julien Alapetite. In parallel, we reviewed the downscaling and regionalizing techniques in the IO literature and looked for the necessary information concerning the Rhône-Alpes region. We concluded that enough data was available in order to carry out downscaling but that data was still too scarce for the finer levels of regionalizing.

6.4. Mapping and land use and land cover change for the ESNET project

The ESNET project (EcoSystem services NETworks) is a collaboration lead by LECA (Laboratoire d'ECologie Alpine, UJF) that aims at characterizing the ecosystem services of the Grenoble urban region (about 2/3 of the Isere département) at the 2030/2040 horizon under various constraints of urban policy planning, changes in agricultural and forest management, and climate change impact on ecosystems. A preliminary task in this research program was the elaboration of very detailed maps (both in terms of land use and of resolution) of the study area at three different dates (1998, 2003 and 2009) based on available satellite and IGN data, in order to characterize past land use patterns as well as agricultural rotation patterns. These have been made and completed at Inria with the hiring of specialized engineers in these tasks, funded by the ESNET program. This exercice informs the next task (land use and land cover change – LUCC – modelling). Hosting this work at Inria was not only logical in terms of the available computer environment, but also useful in terms of visibility of Inria from outside planning agencies.

The LUCC model itself is developed partly at Inria (for modelling expertise) and partly at LECA (for expertise on ecological change drivers). The model development is still underway but in a rather advanced stage. Relevant drivers for urban development have been identified and statistically characterized. The so-called "transition potentials" (which characterize change of land use over a given period of time) are in the process of being calibrated. The next steps involve the completion of this calibration task, the development of relevant scenarios (underway by the whole ESNET collaboration) and projections of land use into the future. Some sensitivity analysis will also be performed in order to characterize the robustness of the model.

6.5. Benchmarking tools for the climate negotiation of GHG emission reduction trajectories

Climate negotiations related to global warming are another important issue of sustainable development. In this framework that is place at international scale we propose a benchmarking tool that is designed to avoid the main limitations of actual negotiation schemes. Our approach is based on the original Soft Landing proposition, made by Criqui and Kouvaritakis in the early 2000. We develop an up to date solution which improves the original idea mainly by introducing common but differentiated emission reduction profiles and by developing a dedicated algorithm for that purpose (called REDEM). To be compatible with global objectives, it is commonly accepted that for most developing regions, the national emission curves should admit a maximum and then should progressively decline. Similarly, we emphasize the fact that, in order to achieve the global objectives, all states will have to entail mitigation efforts, the intensity which may be measured by the rate of variation of the national emissions. At one point, the effort will reach a maximum, when the rate of variation in absolute value is at its maximum, and then decrease. In other words, there will also be a peak in the effort. Then we propose to base the benchmark on this peak of effort. This work has been done in collaboration with EDDEN Laboratory, in particular Patrick Criqui and Constantin Ilasca.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

The PhD thesis of Jean-Yves Courtonne is co-sponsored by ARTELIA and Inria, via a bilateral contract.

Related to the former computer vision research activities of team members, we still had three contracts with EADS Astrium Satellites, where we appear as sub-contractors for one national and two European projects: DECSA (DGA), MREP Camera (European Space Agency), TRP-FUSION (European Space Agency).

8. Partnerships and Cooperations

8.1. Regional Initiatives

In 2012, we started an informal collaboration with Serge Fenet from the University of Lyon (LIRIS lab), which among others accompanied Brindusa Smaranda's MSc thesis. In 2013, a project we submitted to the IXXI Complex Systems Institute of the Rhône-Alps region, together with the CERAG lab, was accepted. The project is about modeling and data mining applied to territorial ecology.

8.2. National Initiatives

8.2.1. ANR

CITiES (*Calibrage et valIdation de modèles Transport - usagE des Sols*)

Program: "*Modèles Numériques*" 2012, ANR
Duration: 2013 – 2016
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.

8.2.2. FRB (Fondation pour la Recherche sur la Biodiversité)

ESNET (Futures of ecosystem services networks for the Grenoble region)

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 – 2016
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.

8.3. International Initiatives

8.3.1. Participation In other International Programs

TRACER (*TRANUS, analyse de la calibration et des erreurs, retours sur Grenoble et Caracas*)
Program: Ecos-NORD
Duration: 2012 – 2014
Coordinator: Mathieu Saujot (IDDRI)
Other partners: University of Caracas (Venezuela)

8.4. International Research Visitors

8.4.1. Visits of International Scientists

In July 2013, we received a one week visit by Professor Tomás de la Barra (University of Caracas and Modelistica) and by Dr. Brian Morton (University of North Carolina), the two leading experts of the TRANUS model (de la Barra developed the model). We organized a 3-day training course on the TRANUS model around these visits, with attendees from various labs in France and Belgium as well as an extended visit to the urban planning agency of the Grenoble region.

8.4.2. Internships

Participant: Thomas Capelle.
Subject: Calibration of the TRANUS land use module
Date: from Apr 2013 until Aug 2013
Institution: Universidad de Chile, Santiago

Participant: Lara Antonela Colombo.
Subject: Optimization based formulation of local material flow assessment
Date: from Mar 2013 until Aug 2013
Institution: Universidad National de Rosario (Argentina)

Participant: Martin Crespo.
Subject: Parameter optimization algorithm for a Transport/land use model via adjoint method.
Date: from Jul 2012 until Jan 2013
Institution: Universidad National de Rosario (Argentina)

Participant: Laurent Gilquin.
Subject: Sensitivity analysis of TRANUS
Date: from Mar 2013 until Aug 2013
Institution: ENS Lyon

Participant: Jakub Krzywda.
Subject: Data mining for ecological accounting and material flow analysis
Date: from Mar 2013 until Aug 2013
Institution: Poznan University of Technology (Poland)

Participant: Brindusa Smaranda.

Subject: Data mining for ecological accounting and material flow analysis

Date: from Mar 2013 until Aug 2013

Institution: Erasmus Mundus on Data Mining Knowledge Management (Lyon and Barcelona)

Participant: Pablo Virgolini.

Subject: Optimization based formulation of local material flow assessment

Date: from Mar 2013 until Aug 2013

Institution: Universidad National de Rosario (Argentina)

9. Dissemination

9.1. Scientific Animation

P. Sturm is Associate Editor of the IEEE Transactions on Pattern Analysis and Machine Intelligence, the Journal of Mathematical Imaging and Vision, and the Image and Vision Computing Journal.

P. Sturm co-edited, with S. Garlatti and O. Boissier, a special issue in Revue d'Intelligence Artificielle *with the best AI papers of the conference RFIA 2012.*

P. Sturm co-edited, with S. Garlatti, a special issue in Traitement du Signal *with the best pattern recognition and computer vision papers of the conference RFIA 2012.*

P. Sturm is member of the Scientific Council of the foundation Barcelona Media.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

P. Sturm, Informatique visuelle, 37.5h, M2, University of Grenoble, France.

P. Sturm, Computer vision, 13.5h, M2, University of Grenoble, France.

9.2.2. Supervision

PhD in progress:

Julien Alapetite, Pilotage d'une collectivité avec l'empreinte écologique, part-time PhD student who carries out part of his work in STEEP, graduation expected in 2014, advisor D. Dupré (CERAG)

Thomas Capelle, Research on optimization methods for setting up integrated models of transportation and land use, started in October 2013, P. Sturm and A. Vidard (MOISE)

Jean-Yves Courtonne, Analyse d'impacts environnementaux et aide à la décision sur des territoires locaux, du bassin d'emploi à la région, started in 2013, P.-Y. Longaretti and D. Dupré (CERAG)

Laurent Gilquin, Sensitivity analysis of a macroeconomic LUTI model, started in October 2013, E. Arnaud and C. Prieur (MOISE)

Anthony Tschirhard, Calibration and sensitivity analysis of a micro-simulation LUTI model, Oct 2012, E. Prados, E. Arnaud, P. Sturm

9.2.3. Juries

P. Sturm, President of the AFRIF Thesis Award Committee (French Association for Research in Pattern Recognition and Interpretation)

P. Sturm, Member of habilitation committee, Christophe Cudel, Universite de Haute-Alsace, Mulhouse

P. Sturm, Reviewer of PhD thesis, Laurent Caraffa, Paris 6

P. Sturm, Reviewer of PhD thesis, Pedro Miraldo, Coimbra University, Portugal

P. Sturm, Reviewer of PhD thesis, Christian Unger, Technische Universität München, Germany

P. Sturm, President of PhD committee, Jordi Sanchez-Riera, Grenoble University

P. Sturm, President of PhD committee, Marion Decrouez, Grenoble University

P. Sturm, President of PhD committee, David Ok, école des Ponts ParisTech

9.3. Popularization

STEEP participated in the 2013 edition of the technological fair “Forum 4i” of the Rhône-Alps region, which was on “Intelligent mobility, usages and innovations”. The forum is visited by local and regional politicians and other stakeholders as well as by the general public. We presented the activities of the team and the socio-economic issues that motivate them.

Emmanuel Prados has been invited to give the introductory talk of the conference “Journée des Mathématiques”of Grenoble organized by the “Rectorat de Grenoble” (Grenoble, March 18, 2013; Title of the presentation: “Préserver l’environnement avec l’aide des mathématiques”).

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] P. DUTTA, E. ARNAUD, E. PRADOS, M. SAUJOT. *Calibration of an Integrated Land-Use and Transportation Model Using Maximum-Likelihood Estimation*, in "IEEE Transactions on Computers", January 2014, vol. 63, n^{o} 1, pp. 167-178 [*DOI :* 10.1109/TC.2013.168], http://hal.inria.fr/hal-00748555

[2] M. DÍAZ, P. STURM. *Estimating Photometric Properties from Image Collections*, in "Journal of Mathematical Imaging and Vision", September 2013, vol. 47, n^{o} 1-2, pp. 93-107 [*DOI :* 10.1007/s10851-013-0442-7], http://hal.inria.fr/hal-00825593

[3] L. PUIG, P. STURM, J. GUERRERO. *Hybrid Homographies and Fundamental Matrices Mixing Uncalibrated Omnidirectional and Conventional Cameras*, in "Machine Vision and Applications", May 2013, vol. 24, n^{o} 4, pp. 721-738 [*DOI :* 10.1007/s00138-012-0424-6], http://hal.inria.fr/hal-00746469

International Conferences with Proceedings

[4] E. ARNAUD, P.-Y. LONGARETTI, E. PRADOS, P. STURM. *Modelling for local scale sustainability and decision-making support: reflections and difficulties*, in "Flow modeling for urban planning", Lille, France, G. HÉGRON (editor), IFSTTAR, 2013, pp. 41-51, http://hal.inria.fr/hal-00748618

[5] V. CHARI, P. STURM. *A Theory of Refractive Photo-Light-Path Triangulation*, in "CVPR 2013 - IEEE Conference on Computer Vision and Pattern Recognition", Portland, United States, IEEE, June 2013, pp. 1438-1445 [*DOI :* 10.1109/CVPR.2013.189], http://hal.inria.fr/hal-00880470

[6] D. Herrera Castro, J. Kannala, P. Sturm, J. Heikkilä. *A learned joint depth and intensity prior using Markov Random fields*, in "3DV 2013 - International Conference on 3D Vision", Seattle, United States, IEEE, 2013, pp. 17-24 [*DOI :* 10.1109/3DV.2013.11], http://hal.inria.fr/hal-00880486

Scientific Books (or Scientific Book chapters)

[7] S. Garlatti, P. Sturm, O. Boissier. , *Reconnaissance des formes et intelligence Artificielle (Revue d'intelligence artificielle, vol. 27, n°1, 2013)*, Hermes, Lavoisier, 2013, 144 p. , http://hal.inria.fr/hal-00812476

[8] P.-Y. Longaretti. *Changements globaux*, in "Le développement durable à découvert", A. Euzen, L. Eymard, F. Gaill (editors), A découvert, CNRS éditions, September 2013, pp. 40-41, http://hal.inria.fr/hal-00934342

[9] P. Sturm. *Calibration of a non-single viewpoint system*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00759938

[10] P. Sturm. *Fisheye lens*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00759935

[11] P. Sturm. *Focal length*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00759934

[12] P. Sturm. *Image plane*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00784185

[13] P. Sturm. *Omnidirectional vision*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00789333

[14] P. Sturm. *Optical axis*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00788369

[15] P. Sturm. *Pinhole camera model*, in "Computer Vision: A Reference Guide", K. Ikeuchi (editor), Springer, 2014, http://hal.inria.fr/hal-00794084

Research Reports

[16] J. Krzywda, P. Sturm. , *Calculating indices for urban sprawl*, Inria, November 2013, n° RR-8398, http://hal.inria.fr/hal-00907081

Other Publications

[17] P. Dutta, A. Halder, R. Bhattacharya. , *Nonlinear Estimation with Perron-Frobenius Operator and Karhunen-Loeve Expansion*, 2013, under review, http://hal.inria.fr/hal-00773533

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