



IN PARTNERSHIP WITH:
CNRS

**Université Pierre Mendès-France
(Grenoble)**

Activity Report 2015

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

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

Keywords:

Computer Science and Digital Science:

- 3.3.2. - Data mining
- 6.1. - Mathematical Modeling
- 8.6. - Decision support

Other Research Topics and Application Domains:

- 1.2. - Ecology
 - 1.2.1. - Biodiversity
- 3.1. - Sustainable development
 - 3.1.1. - Resource management
- 3.4.3. - Pollution
- 7. - Transport and logistics
- 8.3. - Urbanism and urban planning
- 8.5.1. - Participative democracy
- 8.5.3. - Collaborative economy
- 9.10. - Ethics

1. Members

Research Scientists

Emmanuel Prados [Team leader, Inria, Researcher, HdR]
Pierre-Yves Longaretti [CNRS, Researcher]
Peter Sturm [Inria, Senior Researcher, HdR]

Faculty Members

Elise Arnaud [Univ. Grenoble I, Associate Professor]
Denis Dupre [Univ. Grenoble II, Associate Professor]
Serge Fenet [Univ. Lyon I, Associate Professor]

PhD Students

Thomas Capelle [Inria, granted by ANR CITIES project]
Jean-Yves Courtonne [Inria]
Luciano Gervasoni [Univ. Grenoble I]

Post-Doctoral Fellow

Fausto Lo Feudo [IFSTTAR, from Feb 2015]

Administrative Assistant

Marie-Anne Dauphin-Rizzi [Inria]

Others

Solange Blundi [Inria, Internship, until Jan 2015]
Bérangère Deforche [Inria, Internship, from Feb 2015 until Jul 2015]
Patricio Inzaghi [Inria, Internship, until Jan 2015]
Bappa Muktar [Inria, Internship, from Mar 2015 until Aug 2015]
Julien Alapetite [PhD, until Jun 2015]

Brian Morton [Visiting Scholars, Sep 2015]

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), 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. A second LUTI model that will be considered in the near future, within the CITiES project, is UrbanSim⁵. 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/

⁵<http://www.urbansim.org>

land cover change (LUCC) modelling environments (LCM from Clark labs ⁶, and Dinamica ⁷) which belongs to the category of spatially explicit statistical models.

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

3.2. Model calibration and validation

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

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

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

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

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

⁶<http://www.clarklabs.org/products/Land-Change-Modeler-Overview.cfm>

⁷<http://www.csr.ufmg.br/dinamica/>

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 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.

4. Highlights of the Year

4.1. Highlights of the Year

The adventure continues!

The start of STEEP as an exploratory action in 2010 constituted a significant thematic change for all its members. This risky adventure was successfully consolidated in 2015, with the acceptance of STEEP as a full project-team. The adventure continues!

Various significant contributions

In other respects, two important results have been obtained this year on the ecological accounting front. First, a generic method of evaluation of environmental pressures from material flows has been developed and published (paper in press at the time of writing). Second, the errors associated to the national transport database which is heavily used in material flow analysis have been quantified; this work will be published in 2016 but is eagerly awaited by a number of researchers and agencies, as the disaggregated error is not evaluated in the database itself.

As a by-product of its investment in the ESNET project (Ecosystem Services Network), the team has developed an important expertise on the methodological aspects of LUCM modelling. This expertise has turned into a theoretical analysis of the foundations of LUCM theory itself, as important methodological flaws and their theoretical cures have been identified in the course of the project. These methodological and theoretical advances will be submitted to publication within the coming year.

Finally, our benchmarking tools designed for climate negotiations have been used by the “*Groupe Interdisciplinaire sur les Contributions Nationales*” (GICN) which has been mandated by french ministry of Sustainable Development to prepare the **climate change conference COP21** at Paris. Some contributions have been presented at the Side Events of COP 21, the 2nd of December 2015. Contributions have been published in a special working paper [11].

5. New Software and Platforms

5.1. QGISTranusReports

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 à 2D or 3D à 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.

- Contact: Peter Sturm

5.2. REDEM

REDUCTION OF EMISSION

FUNCTIONAL DESCRIPTION

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

- Participants: Patrick Criqui, Constantin Ilasca, Olivier Boucher and H el ene Benveniste
- Partners: EDDEN - IPSL
- Contact: Emmanuel Prados
- URL: <http://redem.gforge.inria.fr/>

5.3. Wassily

SCIENTIFIC DESCRIPTION

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.

FUNCTIONAL DESCRIPTION

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 related environmental questions.

- Participants: Julien Alapetite and Jean-Yves Courtonne
- Contact: Julien Alapetite

5.4. Contribution to the R package “sensitivity”

FUNCTIONAL DESCRIPTION

The contribution to the R package “sensitivity” includes the development of the function “sobelroahs” performing global sensitivity analysis of a numerical model. This function implements the estimation of the Sobol’ sensitivity indices introduced by [19] using two Orthogonal Array-based Latin Hypercubes. This function allows the estimation of all first-order indices or all closed second-order indices (containing the sum of the second-order effect between two inputs and the individual effects of each input) at a total cost of $2 \times N$. For closed second-order indices, $N = q^2$ where $q \geq d - 1$ is a prime number denoting the number of levels of the orthogonal array, and where d is the number of factors of the model.

- Participants: Laurent Gilquin, Elise Arnaud, Clémentine Prieur
- Partners: AIRSEA (Inria / UJF)
- Contact: Laurent Gilquin
- URL: <https://cran.r-project.org/web/packages/sensitivity/index.html>

6. New Results

6.1. Methods for the calibration of LUTI models

The setting up of a LUTI model requires, like most numerical models, at least one phase of parameter estimation. This is concisely referred to here as calibration, although the calibration of a LUTI model also entails other aspects such as the definition of spatial zones, of economic sectors, etc. The TRANUS LUTI model plus software, like many other existing models, come along with a relatively simple calibration methodology. Most LUTI models indeed perform parameter estimation in a piecewise fashion, by sequentially estimating subsets of parameters. While this reduces the mathematical and computational complexity of calibration, neglecting the interactions across different modules and their parameters, may result in a significant loss of a model’s quality. A second issue is that TRANUS, like several other LUTI softwares, employs rudimentary numerical routines for parameter estimation. We aim at reducing these weaknesses.

In 2014, we had obtained first results along these lines: parameter estimation of the so-called shadow prices (specific parameters of the TRANUS model) was posed as optimization problem and several solution procedures were developed which were based on “unwinding” the dynamics of the model, making the problem amenable to standard numerical optimisation techniques.

The work continued throughout 2015, along different directions. First, the calibration was extended to handle several different parameter types simultaneously (shadow prices as well as the so-called substitution parameters, which are notoriously difficult to estimate) [7]. Such a simultaneous estimation of different parameter sets seems to be rare in LUTI practice.

Second, we proposed a methodology for assessing properties (convergence, accuracy) of our (and other) LUTI calibration methods [6]. This consists in generating synthetic data, starting from a model calibrated on observed data, such that the synthetic data are completely consistent, i.e. there are a set of model parameters that exactly reproduce these data (which is not the case with the observed data). The ground truth model parameters are then easily used to assess calibration parameters. Such a methodology, akin to twin experiments in data assimilation, seems to be novel for LUTI research.

Third, LUTI models are usually calibrated on a base year or period, and used in a prospective manner (via simulated “predictions” for future periods). As with any numerical model, it is wise to make sure that a calibrated LUTI model does not overfit the observations used for calibration; otherwise, its “predictions” may be grossly erroneous. Potential overfitting does not seem to have been deeply studied in the LUTI literature. We have made an initial investigation by calibrating different versions of a TRANUS model, varying the number of shadow prices used as parameters in the model (there is, by default, one shadow price per combination of geographical zone of the study area and economic sector) [6]. For instance, after an initial calibration using all

shadow prices, we then dropped the two third smallest of them and re-calibrated the model using the remaining third. The goodness-of-fit to observations was worse by only 3%. In line with well-known principles of model selection (Occam's razor), this may suggest that it is preferable to use the model with fewer parameters when doing predictions. This is still work in progress; showing its relevance is planned to be studied by a similar methodology as above, using simulated twin experiments.

This work is done in collaboration with Arthur Vidard from the AIRSEA Inria project-team and Brian Morton from the University of North Carolina at Chapel Hill.

6.2. Estimation of Sobol' indices combining nested designs and replication method

Sensitivity analysis studies how the uncertainty on an output of a mathematical model can be attributed to sources of uncertainty among the inputs. Global sensitivity analysis of complex and expensive mathematical models is a common practice to identify influent inputs and detect the potential interactions between them. Among the large number of available approaches, the variance-based method introduced by Sobol' allows to calculate sensitivity indices called Sobol' indices. Each index gives an estimation of the influence of an individual input or a group of inputs. These indices give an estimation of how the output uncertainty can be apportioned to the uncertainty in the inputs. One can distinguish first-order indices that estimate the main effect from each input or group of inputs from higher-order indices that estimate the corresponding order of interactions between inputs. This estimation procedure requires a significant number of model runs, number that has a polynomial growth rate with respect to the input space dimension. This cost can be prohibitive for time consuming models and only a few number of runs is not enough to retrieve accurate informations about the model inputs.

The use of replicated designs to estimate first-order Sobol' indices has the major advantage of reducing drastically the estimation cost as the number of runs becomes independent of the input space dimension. The generalization to closed second-order Sobol' indices relies on the replication of randomized orthogonal arrays. However the replication method still requires a large number of model evaluations. By rendering this method iterative, the required number of evaluations can be controlled. The estimation procedure is therefore stopped when the convergence of estimates is considered reached. The key feature of this approach is the construction of nested designs. For the estimation of first-order indices, we exploit a nested Latin Hypercube already introduced in the litterature. For the estimation of closed second-order indices, two methods are proposed to construct a nested orthogonal array. One of the two leads to a partition of the coordinate space over a Galois field.

This work has been done in collaboration with Laurent Gilquin and Clementine Prieur (members of Moise Team), and belongs to the work program of CiTIES project. The proposed procedure will be soon applied to study the sensitivity of TRANUS model.

6.3. Environmental pressures associated with material flows

This work is the follow-up of a previous study dedicated to material flow analysis of the French cereal supply chain at various spatial levels [12]. The goal was twofold:

- trace the flows to their initial geographic origin or final destination,
- couple material flows with a series of environmental pressures associated to them.

For the first goal, we used an Absorbing Markov Chains model where transient states represent raw or semi-products and absorbing states correspond to final consumption products. For the second goal, we used pressure ratios for environmental pressures most relevant to cereals, namely energy use, GHG emissions, land use, use of pesticides and blue water footprint. The model is based on physical supply and use tables and distinguishes between 21 industries, 22 products, 38 regions of various spatial resolution (22 French regions, 10 countries, 6 continents) and 4 modes of transport. Illustrative examples were taken in order to demonstrate the versatility of the results produced, for instance: What is the fate/supply area of a region's production/consumption? What are the production and consumption footprint of a region? These results are designed to be a first step towards scenario analysis for decision-aiding that would also include socioeconomic indicators [13]

6.4. Material flows of the French forest-wood supply chain

The methodology developed in Courtonne et al. [12] on the case of the cereal supply chain was adapted to the French forest-wood supply chain in collaboration with the Laboratoire d'Economie Forestière. Supply chain flows were estimated both at the national and regional scale for wood harvest, addition to stock, production, imports and exports of construction wood, industrial wood and energy wood. These results can be a basis to analyze potential value losses throughout the supply chain, for instance exports of raw materials instead of local transformation. They can also be used to study the competitive use of wood for energy, industry and construction/furnitures, which is a question of growing importance in the context of energy transition.

6.5. Land Use/Land Cover Change (LUCC) Modelling and Ecosystem Services

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 Isère département) at the 2040 horizon under various constraints of urban policy planning, changes in agricultural and forest management, and climate change impact on ecosystems.

The cartographic effort of the project has been hosted at Inria, and has produced in 2014 three very detailed maps of land use and land cover at the 15m resolution over the whole study area, in 1998, 2003 and 2009, respectively. An extensive analysis of the patterns of landscape change has been performed from these data, with special emphasis on urban sprawl and the associated loss of arable land. This work has been submitted for publication very recently.

A second related piece of work has been produced, both from this cartographic source and more specific remote sensing data. The objective was to characterize in detail the cultural successions and patterns of the study area, in order to produce fine scale maps of associated ecosystem services. This work has just been submitted for publication at the time of writing.

Finally, the scenarios of future land use and land cover that have been elaborated for this project have all been projected at the 2040 horizon at the 15m scale with a well-known LUCC modelling environment (Dinamica) for urban changes, and from in-project models for the other types of land use and cover. A third article bearing on these scenarios and their LUCC modelling is in preparation.

As an aside of this land use/cover modelling effort, the STEEP team has been involved in two of the most detailed ecosystem service models developed for the project: one for the analysis of crop production and associated nitrogen cycle assessment — with the final aim to constrain both the production services and water quality issue related to nitrogen loading — and one on “recreational services”. Our involvement in these models was directly related to the acquired expertise in land use modelling.

In the process of this modelling exercise, the STEEP team has acquired an in-depth knowledge and expertise of LUCC models. As a consequence, various theoretical flaws have been identified in the theoretical foundations of such models. An important by-product of the ESNET project is therefore a series of articles in preparation in the team, whose aim is to address and correct these flaws in a very general way; it is hoped that LUCC theory will be put on a more serious theoretical footing as a result of this methodological work, which should be submitted for publication in 2016 for the most part. Another but more limited methodological contribution bears on the development of error models for landscape metrics, another important methodological blind-spot in the specialized literature.

6.6. A benchmarking tool to assess the compatibility of the INDCs with the 2°C long-term target

Climate negotiations related to global warming are another important issue of sustainable development. In this framework that is place at international scale we have developed a benchmarking tool which allows to assess the compatibility of the Intended Nationally-Determined Contributions (INDCs) given by all states for the Conference COP21, with the 2°C long-term target. This benchmarking tool has been designed via an adaptation of REDEM model and algorithm we developed in 2014 with EDDEN laboratory. This tool has been

used by the “*Groupe Interdisciplinaire sur les Contributions Nationales*” (GICN) which has been mandated by french ministry of Sustainable Development to prepare the climate change conference COP21 at Paris.

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 one contract with EADS Astrium Satellites (now Airbus Defence and Space), where we appear as sub-contractor: DECSA (DGA).

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

CITIÉS (*Calibrage et validation de modèles Transport - usagE des Sols*)

Program: “*Modèles Numériques*” 2012, ANR

Duration: 2013 – 2016

Coordinator: Emmanuel Prados (STEPP)

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.

8.1.2. 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.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. General chair, scientific chair

Peter Sturm co-chaired, together with François Sillion, the program committee of the annual edition of the Inria Science Days, held in Nancy.

9.1.2. Scientific events selection

9.1.2.1. Member of the conference program committees

Peter Sturm was a member of the program committees of the German Conference on Pattern Recognition and the Journées Jeunes Chercheurs ORASIS.

Emmanuel Prados was a member of the program committees of IJCAI 2015 CompSust track (International Joint Conference on Artificial Intelligence), Buenos Aires, Argentina, 2015.

9.1.3. Journal

9.1.3.1. Member of the editorial boards

Until 2015, Peter Sturm was member of the editorial boards of the IEEE Transactions on Pattern Analysis and Machine Intelligence, the Image and Vision Computing Journal, and the Journal on Mathematical Imaging and Vision.

9.1.4. Invited talks

Peter Sturm gave seminars at Lund University and the Université de Bourgogne.

Denis Dupré gave a conference at the special event of COP 21 called “SOLUTIONS COP21 Paris 2015” [Grand Palais, Paris, France]. Conference title: “Les outils économiques et financiers du développement durable en débat”, December 10, 2015.

Denis Dupré gave a conference at the “journées scientifiques de l’Inria” Conference title: “Les hommes maitres du chaos climatique ? Citoyens et institutions face à la simulation scientifique”, Nancy, June 18, 2015.

Emmanuel Prados gave a conference at the Séminaire In’Tech “*Inventer de nouveaux produits et services répondant à l’évolution de la société*”. Conference title: “*Outils d’analyse des pressions environnementales des territoires pour une mise en oeuvre de politiques de développement durable*”, Montbonnot, 5th of Oct, 2015.

9.1.5. Scientific expertise

Peter Sturm is member of the scientific council of the Barcelona Media foundation.

Emmanuel Prados is member 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 2015.

9.1.6. Research administration

Since mid-2015, Peter Sturm is one of the five Deputy Scientific Directors of Inria. Until mid-2015, he was a member of the Scientific Committee of Inria Grenoble Rhône-Alpes.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

License : E. Arnaud, Mathematics for engineer, 50h, L1, University of Grenoble, France.

License : E. Arnaud, Mathematics upgrade, 14h, L1, University of Grenoble, France.

Master : E. Arnaud, Advising students on apprenticeship, 28h, M2, University of Grenoble, France.

Master : E. Arnaud, Programming project in image processing, 20h, M1, University of Grenoble, France.

Master : E. Arnaud, Image processing, 18h, M2, University of Grenoble, France.

GRETSI Summer school : E. Prados, “*Les véritables enjeux environnementaux, modélisations et outils quantitatifs*”, 3-hour course, France, 21-27th of June, 2015. <http://www.gretsi.fr/peyresq15/>

Pedagogical resources : Elise Arnaud, Mathematics for engineer, L1, University of Grenoble, France. (video <http://tinyurl.com/youtube-mat126>, all documents for problem-based learning)

9.2.2. Supervision

PhD in progress: Thomas Capelle, “LUTI Calibration as Optimization Problem and Algorithms for Solving them”, 2013, Peter Sturm and Arthur Vidard (AIRSEA).

PhD in progress: Luciano Gervasoni, “Data mining for integrated land use and transportation models”, 2015, Peter Sturm and Serge Fenet (LIRIS, Lyon).

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

PhD in progress: 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 Spring 2014. Denis Dupré (CERAG/UGA and STEEP/Inria) and Pierre-Yves Longaretti (IPAG/UGA and STEEP/Inria), PhD advisors.

PhD in progress: Coline Byczek, “Analyse de réseaux de services écosystémiques dans le bassin d’emploi grenoblois”, started in 2012. Sandra Lavorel (LECA/UGA) and Pierre-Yves Longaretti (IPAG/UGA and STEEP/Inria), PhD advisors.

PhD in progress: Rémy Lasseur, “Modélisation et cartographie multi-échelles des faisceaux de services écosystémiques”, started in Fall 2014. Sandra Lavorel (LECA/UGA) and Pierre-Yves Longaretti (IPAG/UGA and STEEP/Inria), PhD advisors.

Internship: Bérangère Deforche work objective was to characterize the potential of organic farming in the Grenoble area. The motivation of this work was to evaluate if the growing demand on this front could be supplied locally, and more generally assess the extent of potential autonomy of the Grenoble area in terms of basic staple supply. The internship included a component on the potential of urban agricultural production, which eventually became the most important part of the work due to lack of time. The results obtained in this work are disappointing, due to a lack of mastery of GIS tools on the part of the student, and her slow learning curve.

Internship: Bappa Muktar worked on the development of software Wassily for environmental-extended input-output analysis. In particular, he documented the existing code and the installation process of the various modules needed on both PC and Mac platforms. He then worked on the database and matrix computation modules and tested them with real datasets (e.g. French Input-Output table coupled with CO2 emissions by economic sector).

Internship: Solange developed animations for explaining 3D computer vision algorithms, a work related to the previous research domain of Peter Sturm who supervised this internship.

Internship: Patricio developed the QGIS_Transus_Reports software, see above.

9.2.3. Juries

Peter Sturm was reviewer for the following PhD theses:

- Danda Pani Paudel, Université de Bourgogne.
- Dongming Chen, Ecole Centrale de Lyon.
- Sebastian Haner, Lund University, Sweden.

9.3. Popularization

Peter Sturm coordinated, together with Antoine Rousseau (LEMON) and the Direction for Communication, Inria’s involvement in the general audience fair dedicated to public research institutions, associated with the COP21 Climate Summit held in December 2015 in Paris. Denis Dupré gave a talk at this event and he and Peter Sturm were part of Inria’s delegation at the French research institution’s booth, presenting the work of STEEP and Inria to the public.

Emmanuel Prados gave a conference-debat at “Marie Reynoard” High school on “Sustainable development, territorial governance and democracy” (Villard-Bonnot, France, 21th of December, 2015).

In the context of the GICN (“*Groupe Interdisciplinaire sur les Contributions Nationales*”) and the climate change conference COP21, Emmanuel Prados have participated in the writing of various newspaper articles [17], [18], [15], [16].

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

- [1] T. CAPELLE, P. STURM, A. VIDARD. *Formulating LUTI Calibration as an Optimisation Problem: Example of Transus Shadow Price Estimation*, in "Procedia Engineering", 2015, vol. 115, pp. 12-20 [DOI : 10.1016/J.PROENG.2015.07.349], <https://hal.inria.fr/hal-01237639>
- [2] L. GILQUIN, C. PRIEUR, E. ARNAUD. *Replication procedure for grouped Sobol' indices estimation in dependent uncertainty spaces*, in "Information and Inference", August 2015, vol. 4, n^o 4, pp. 354-379 [DOI : 10.1093/IMAIAI/IAV010], <https://hal.inria.fr/hal-01045034>

Invited Conferences

- [3] D. DUPRÉ, P.-Y. LONGARETTI, J.-M. SERVET. *Fonctions valeurs et leviers d'une monnaie alternative pour une transition à la durabilité territoriale*, in "5ème congrès de l'Association Française d'Economie Politique (AFEP) « L'économie politique de l'entreprise : nouveaux enjeux, nouvelles perspectives »", Lyon, France, AFEP, July 2015, <https://hal.archives-ouvertes.fr/hal-01163553>

International Conferences with Proceedings

- [4] E. PRADOS, P. CRIQUI, C. ILASCA. *A Benchmarking Tool for the International Climate Negotiations*, in "AAAI-15 Special Track on Computational Sustainability", Austin, United States, January 2015, <https://hal.inria.fr/hal-01101210>
- [5] M. SAUJOT, M. DE LAPPARENT, E. ARNAUD, E. PRADOS. *To make LUTI models operationnal tools for planning*, in "International Conference on Computers in Urban Planning and Urban Management (CUPUM)", Cambridge, United States, June 2015, <https://hal.inria.fr/hal-01147315>

Conferences without Proceedings

- [6] T. CAPELLE, P. STURM, A. VIDARD, B. MORTON. *Contributions to the calibration of integrated land use and transportation models*, in "14th International Conference on Computers in Urban Planning and Urban Management", Boston, United States, July 2015, <https://hal.inria.fr/hal-01237628>
- [7] T. CAPELLE, P. STURM, A. VIDARD, B. MORTON. *Formulating LUTI Calibration As an Optimisation Problem: Estimation of Transus Shadow Price and Substitution Parameters*, in "AAAI-15 Workshop on Computational Sustainability", Austin, Texas, United States, January 2015, <https://hal.inria.fr/hal-01237622>
- [8] N. COULOMBEL, P. STURM. *A Survey on the Calibration and Validation of Integrated Transportation and Land Use Models*, in "62nd Annual North American Meetings of the Regional Science Association International", Portland, Oregon, United States, November 2015, <https://hal.inria.fr/hal-01237647>

- [9] D. DUPRÉ, J.-F. PONSOT, J.-M. SERVET. *Bitcoin against the revolution of commons*, in "5ème congrès de l'Association Française d'Economie Politique (AFEP) « L'économie politique de l'entreprise : nouveaux enjeux, nouvelles perspectives », Jul 2015, Lyon, France", Lyon, France, AFEP, July 2015, <https://hal.archives-ouvertes.fr/hal-01169131>
- [10] J. GIPPET, C. ROCABERT, S. FENET, A. DUMET, B. KAUFMANN. *Modeling and evaluating human-mediated dispersal mechanisms at landscape scale: a study of road network and invasion parameters for *Lasius neglectus* ants invasive species*, in "World Conference on Natural Resource Modeling", Bordeaux, France, June 2015, <https://hal.archives-ouvertes.fr/hal-01242828>

Other Publications

- [11] H. BENVENISTE, P. CRIQUI, O. BOUCHER, F.-M. BREON, C. GUIVARCH, E. PRADOS, S. MATHY, L. CHEVALLET, L. COINDOZ, H. LE TREUT. *The INDC counter, aggregation of national contributions and 2°C trajectories*, November 2015, Rapport du groupe interdisciplinaire sur les contributions nationales Institut Pierre Simon Laplace, Climate Modelling Center Scientific Note N°32, 73 p, <http://hal.univ-grenoble-alpes.fr/hal-01245354>
- [12] J.-Y. COURTONNE, J. ALAPETITE, P.-Y. LONGARETTI, D. DUPRÉ, E. PRADOS. *Downscaling material flow analysis: the case of the cereals supply chain in France*, January 2015, working paper or preprint, <https://hal.archives-ouvertes.fr/hal-01142357>
- [13] J.-Y. COURTONNE, P.-Y. LONGARETTI, J. ALAPETITE, D. DUPRÉ. *Environmental pressures embodied in the French cereals supply chain*, April 2015, working paper or preprint, <https://hal.archives-ouvertes.fr/hal-01150067>
- [14] D. DUPRÉ. *Les hommes maitres du chaos climatique ? Citoyens et institutions face à la simulation scientifique*, May 2015, working paper or preprint, <https://hal.archives-ouvertes.fr/hal-01158237>

References in notes

- [15] O. BOUCHER, P. CRIQUI, H. LE TREUT, V. BELLASSEN, H. BENVENISTE, F.-M. BREON, P. CIAIS, T. GASSER, C. GUIVARCH, F. LECOCQ, S. MATHY, E. PRADOS, D. SALAS Y MÉLIA, R. SÉFÉRIAN. *Les contributions nationales soumises à la COP21 appellent à une révision et un suivi des émissions*, in "Huffington Post", November 10th 2015
- [16] D. DUPRÉ, E. PRADOS. *COP21 : 7 pistes pour une Université qui s'engage sérieusement dans le développement soutenable*, in "Huffington Post", November 26th 2015
- [17] H. LE TREUT, O. BOUCHER, V. BELLASSEN, H. BENVENISTE, F.-M. BREON, P. CIAIS, P. CRIQUI, T. GASSER, C. GUIVARCH, F. LECOCQ, S. MATHY, E. PRADOS, D. SALAS Y MÉLIA, R. SÉFÉRIAN. *Pour rejoindre rapidement une trajectoire limitant le réchauffement à 2°C*, in "Le Monde", December 2015
- [18] H. LE TREUT, P. CRIQUI, O. BOUCHER, H. BENVENISTE, F.-M. BREON, P. CIAIS, C. GUIVARCHAND, S. MATHY, E. PRADOS, D. SALAS Y MÉLIA, R. SÉFÉRIAN. *Les contributions nationales avant la COP21 et l'objectif du 2°C*, in "Le Monde - Hors-série. Climat. L'urgence Les enjeux de la COP21 / Alerter / Agir / Innover", November 2015, pp. 63-64
- [19] J.-Y. TISSOT, C. PRIEUR. *Estimating Sobol' indices combining Monte Carlo estimators and Latin hypercube sampling*, October 2012, working paper or preprint, <https://hal.archives-ouvertes.fr/hal-00743964>