Ilab METIS
Optimization of Energy Policies

Olivier Teytaud + Inria-Tao + Artelys

TAO project-team

INRIA Saclay Île-de-France

O. Teytaud, Research Fellow,
olivier.teytaud@inria.fr
http://www.lri.fr/~teytaud/

Outline

Who we are

What we solve

Methodologies

Ilab METIS

www.lri.fr/~teytaud/metis.html

- **Metis = Tao + Artelys**
  - TAO tao.lri.fr, Machine Learning & Optimization
    - Joint INRIA / CNRS / Univ. Paris-Sud team
    - 12 researchers, 17 PhDs, 3 post-docs, 3 engineers
  - Artelys www.artelys.com SME
    - France / US / Canada
    - 50 persons

    ==> collaboration through common platform

- **Activities**
  - Optimization (uncertainties, sequential)
  - Application to power systems

Fundings

- Inria team Tao
- Lri (Univ. Paris-Sud, Umr Cnrs 8623)
- FP7 european project (city/factory scale)
- Ademe Bia(transcontinental stuff)
- Ilab (with Artelys)
- Indema (associate team with Taiwan)
- Maybe others, I get lost in fundings

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Industrial application

- **Building power systems is expensive**
  power plants, HVDC links, networks...
- **Non trivial planning questions**
  - Compromise: should we move solar power to the south and build networks ?
  - Is a HVDC connection “x ↔ y” a good idea ?
- **What we do:**
  - Simulate the operational level of a given power system (this involves optimization of operational decisions)
  - Optimize the investments

Specialization on Power Systems

- **Planning/control**
  - Pluriannual planning: evaluate marginal costs of hydroelectricity
  - Taking into account stochasticity and uncertainties

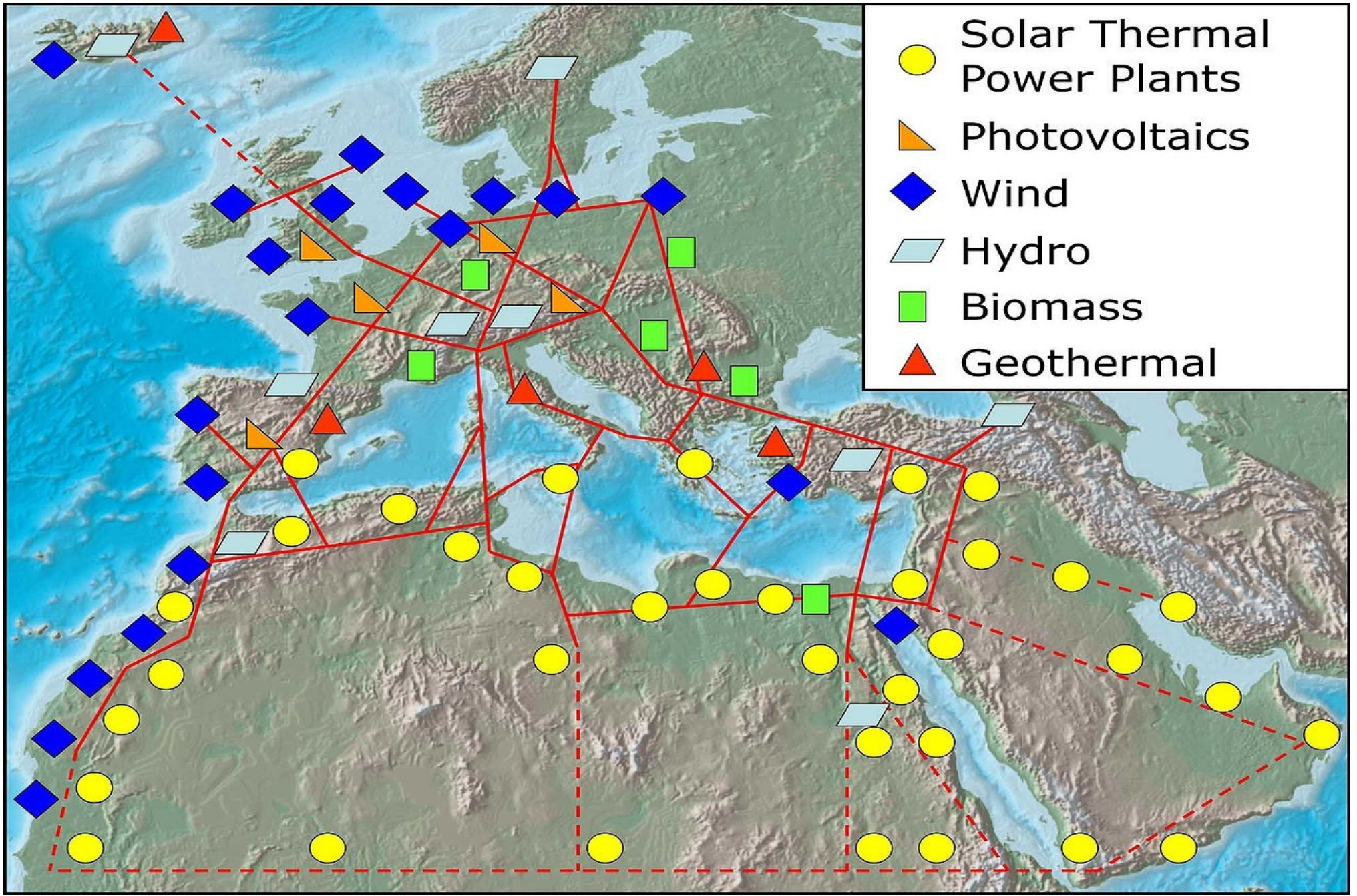
    ==> IOMCA (ANR)

- **High scale investment studies (e.g. Europe+North Africa)**
  - Long term (2030 - 2050)
  - Huge (non-stochastic) uncertainties
  - Investments: interconnections, storage, smart grids, power plants...

    ==> POST (ADEME)
- **Moderate scale (Cities, Factories)**
  - Master plan optimization
  - Stochastic uncertainties

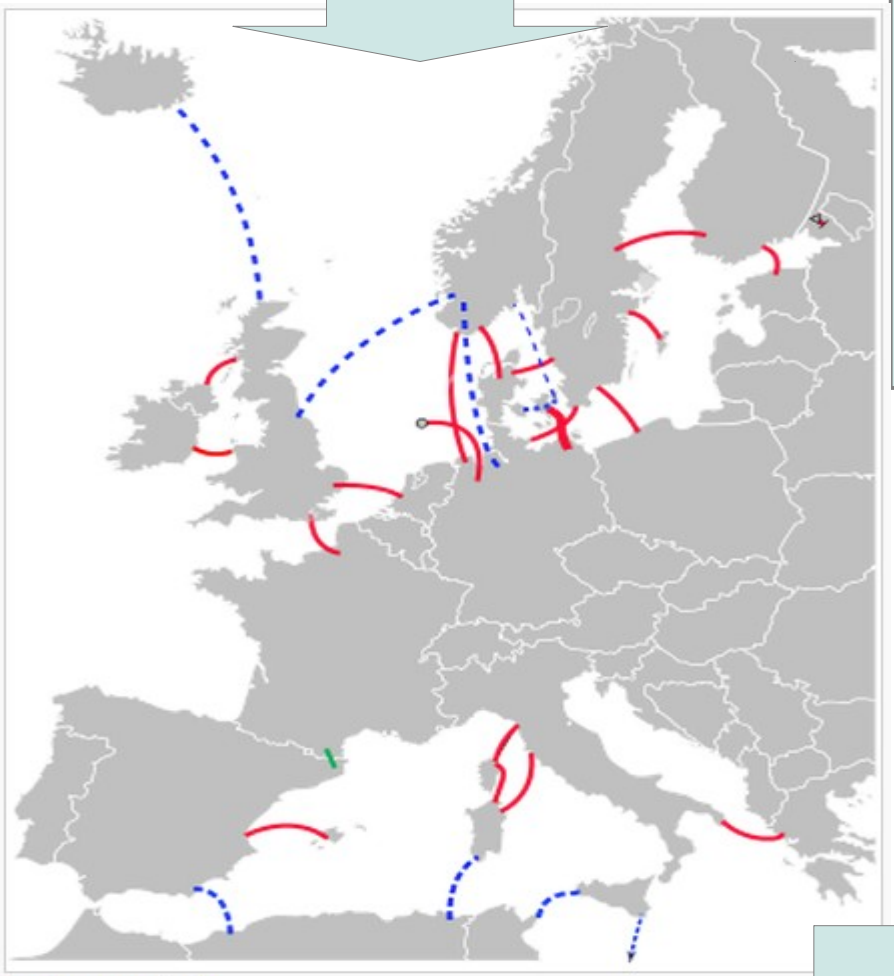
    ==> Citines project (FP7)

Example: interconnection studies
(demand levelling, stabilized supply)



The POST project – supergrids simulation and optimization

Mature technology:HVDC links
(high-voltage direct current)



Existing links
Under construction
Proposed

European subregions:

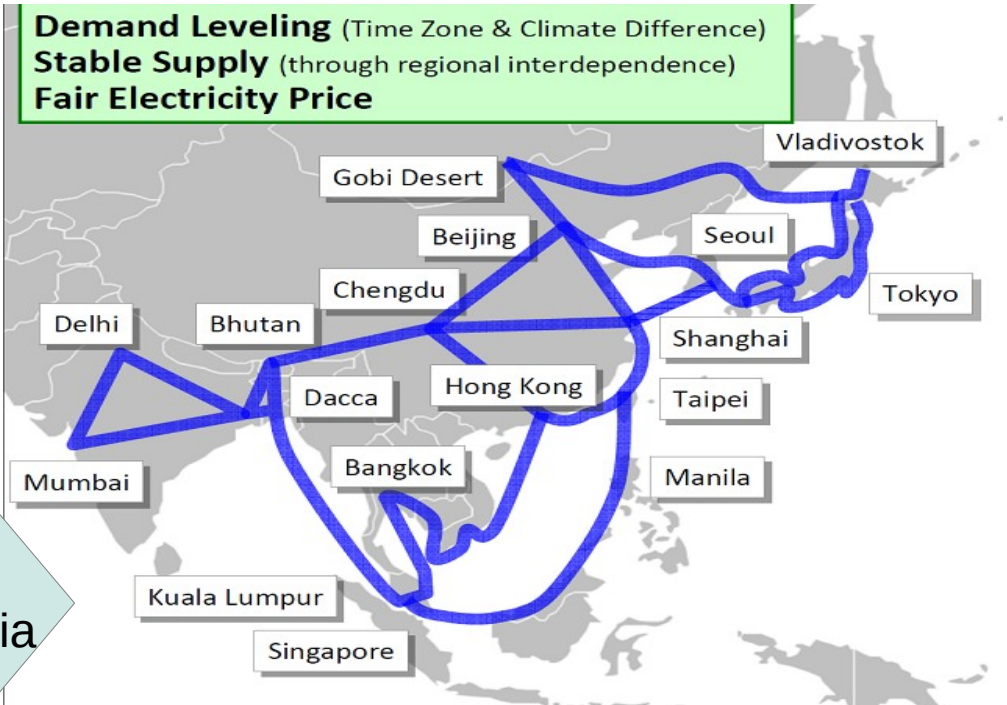
- Case 1 : electric corridor France / Spain / Marocco

- Case 2 : south-west
(France/Spain/Italiy/Tunisia/Marocco)

- Case 3 : maghreb – Central West Europe

==> towards a European supergrid

Related ideas in Asia



Investment decisions through simulations

- **Issues**
  - Demand varying in time, limited previsibility
  - Transportation introduces constraints
  - Renewable ==> variability ++
- **Methods**
  - Markovian assumptions ==> wrong
  - Simplified models ==> Model error >> optimization error
- **Our approach**
  - **Machine Learning** on top of **Mathematical Programming**

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A few milestones

- Linear programming is fast
- Bellman decomposition: we can split
  short term reward + long term reward
- Folklore result: direct policy search

==> we use all of them

Hybridization reinforcement learning / mathematical programming

- **Math programming**
  - Nearly exact solutions for a simplified problem
  - High-dimensional constrained action space
  - But small state space & not anytime
- **Reinforcement learning**
  - Unstable
  - Small model bias
  - Small / simple action space
  - But high dimensional state space & anytime

Errors

- **Statistical error:** due to finite samples (e.g. weather data = archive), possibly with bias (climate change)
- **Statistical model error:** due to the error in the model of random processes
- **Model error:** due to system modelling
- **Anticipativity error:** due to assuming perfect forecasts
- **Monoactor:** due to neglecting interactions between actor (social welfare)
- **Optim. error:** due to imperfect optimization

Plenty of tools

- **Dynamic programming based** ==> bad modelization of long term dependencies

- **Direct policy search:** difficult to handle constraints ==> bad modelization of systems

- **Model predictive control:** bad modelization of randomness

==> we use combined tools

I love Direct Policy Search

- What is DPS ?
  - Implement a simulator
  - Implement a policy / controller
  - Replace constants in the policy by free parameters
  - Optimize these parameters on simulations
- Why I love it
  - Pragmatic, benefits from human expertise
  - The best in terms of model error
  - But ok it is sometimes slow
  - Not always that convenient for constraints

We propose specialized DPS

- A special structure for plenty of constraints
- After all, you can use DPS on top of everything, just by defining a “good” controller
  - DP-based tools have a great representation
  - Let us use DP-representations in DPS

Dynamic programming tools

Decision at time T = argmax of

reward over the T next time steps

+ V'(state) x StateAt(t0+T)

with V computed backwards

Direct Value Search

Decision at time T = argmax of

reward over the T next time steps

Using forecasts as in MPC

+ f(θ, state) x StateAt(t0+T)

As in DPstyle

with θ optimized through Direct Policy Search

and f a general function approximator (e.g. neural)

Summary

- **Model error:** often more important than optim error (whereas most works on optim error)
- We propose methodologies
  - Compliant with constraints
  - More expensive than MPC
  - But not more expensive than DP-tools
  - Smallest model error
  - User-friendly (human expertise)

What we propose

- Is ok for correctly specified problems
  - Uncertainties which can be modelized by probabilities
  - Less model error, more optim. error
  - Optim. error reduced by big clusters
- Takes into account the challenges in new power systems
  - Stochastic effects (increased by renewables)
  - High scale actions (demand-side management)
  - High scale models (transcontinental grids)

What we propose

- Open source ?
  - Algorithms are public
  - Tools are not
  - Data/models are not
- Want to join ?
  - Room for mathematics
  - Room for geeks
  - Room for people who like applications

Our tools

- Tested on real problems
- Include investment levels
  - There are operational decisions
  - There are investment decisions
- Parallel
- Expensive

Further work

- Nothing on multiple actors (national independence ? intern. risk ?)

- Non stochastic uncertainties: how do we modelize non-probabilistic uncertainties on scientific breakthroughs ? (Wald criterion, Savage, Nash, Regret...)

Bibliography

- Dynamic Programming and Suboptimal Control: A Survey from ADP to MPC. *Bertsekas*, 2005. (MPC = deterministic forecasts)
- “Newave vs Odin”: why MPC survives in spite of theoretical shortcomings
- Dallagi et Simovic (EDF R&D) : "Optimisation des actifs hydrauliques d'EDF : besoins métiers, méthodes actuelles et perspectives", PGMO (importance of precise simulations)
- *Ernst*: The Global Grid, 2013
- Renewable energy forecasts ought to be probabilistic! *Pinson*, 2013 (wipfor talk)
- Training a neural network with a financial criterion rather than a prediction criterion. Bengio, 1997
- Direct Model Predictive Control, Decock et al, 2014 (combining DPS and MPC)