PSR

JOINT USE OF LARGE-SCALE STOCHASTIC OPTIMIZATION TECHNIQUES AND HYDROLOGIC MODELING APPLIED TO THE COLUMBIA RIVER SYSTEM

Rafael Kelman
rafael@psr-inc.com

Raphael Chabar
chabar@psr-inc.com

Reservoir System Modeling Technologies Conference
Portland, February 21-22nd 2012

About PSR

- Provider of analytical tools, R&D and consulting services (economics, environmental and finance) in electricity & gas since 1987
- PSR has 40 specialists in engineering, optimization, energy systems, statistics, finance, regulation, environment and IT
- Developer of computational tools for short-, mid- and long-term operation planning, G&T expansion planning and others
- Off-the-shelf and customized solutions for clients in more than 30 countries

Some PSR tools

- SDDP: hydrothermal mid-long term planning
- NCP: short-term scheduling
- OPTGEN: system expansion planning
- NETPLAN: transmission network planning
- CORAL: generation-transmission reliability model
- HERA: hydropower and environmental resource assessment

What is SDDP?

- Probabilistic hydrothermal dispatch model with a detailed representation of generation (hydro, fossil fuel plants and renewables) and transmission
  - Also natural gas production, storage and transportation network
- Study horizons from 1 to 25+ years
  - Weekly or monthly time steps with load blocks in each stage

Hydro modeling

- Detailed topology (hydro cascade) modeling
- Detailed hydro production
- Reservoir security constraints, flood control storage, min/max outflows
- Etc.

Renewable modeling

- Renewable production (wind, biomass, solar etc.) represented by scenarios, which can be correlated to the hydrological / climatic situation

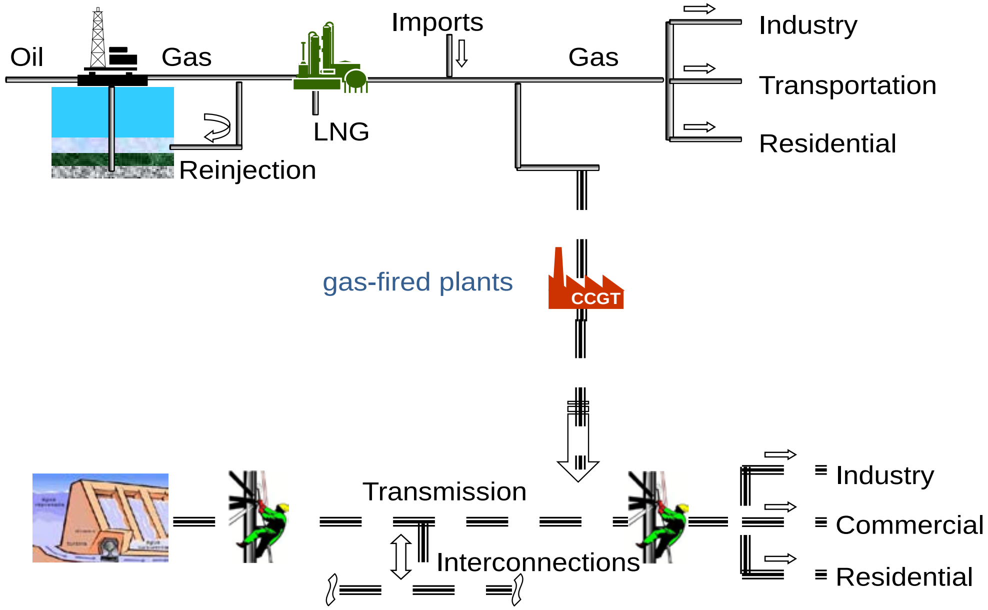
Thermal plant modeling

- Efficiency curves
- Combined cycle thermal plants
- Multiple fuel plants optimization
- Fuel availability constraints
- GHG emission factors
- Unit commitment decisions

Transmission network and loads

- Linearized active power flow model with quadratic losses
  - AC and DC lines represented
- Security constraints: limits on flows, sum of flows (for a set of circuits), area export/import limits etc.
- Bus loads; demand response to prices

Joint E&G modeling



- Gas nodes with production and demand (including thermal power use of natural gas and pipelines with transport limits).
- Gas-fired plants constrained by fuel and transport availability.

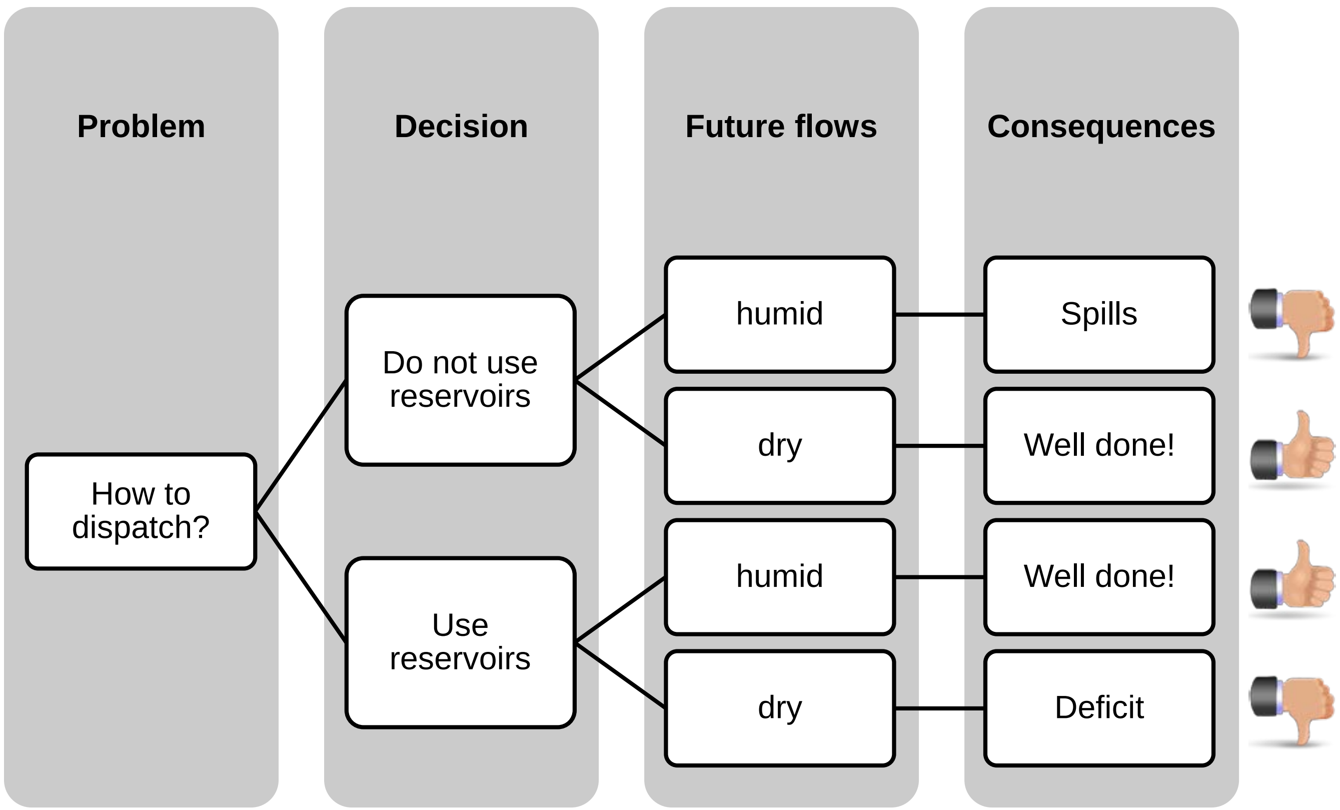
Uncertainties

- PAR-p multivariate stochastic streamflow model
  - Parameters adjusted with basis on historical records of streamflow scenarios produced for example by Reuters Point Carbon
  - Allows handling of macroclimatic events (El Niño), snowmelt and others
- Renewables
  - Scenarios + correlation with hydrological / climatic situation
  - External renewable models can be used to produce scenarios
- G&T equipment outages
  - Monte Carlo sampling
- Fuel cost uncertainty
  - Scenarios

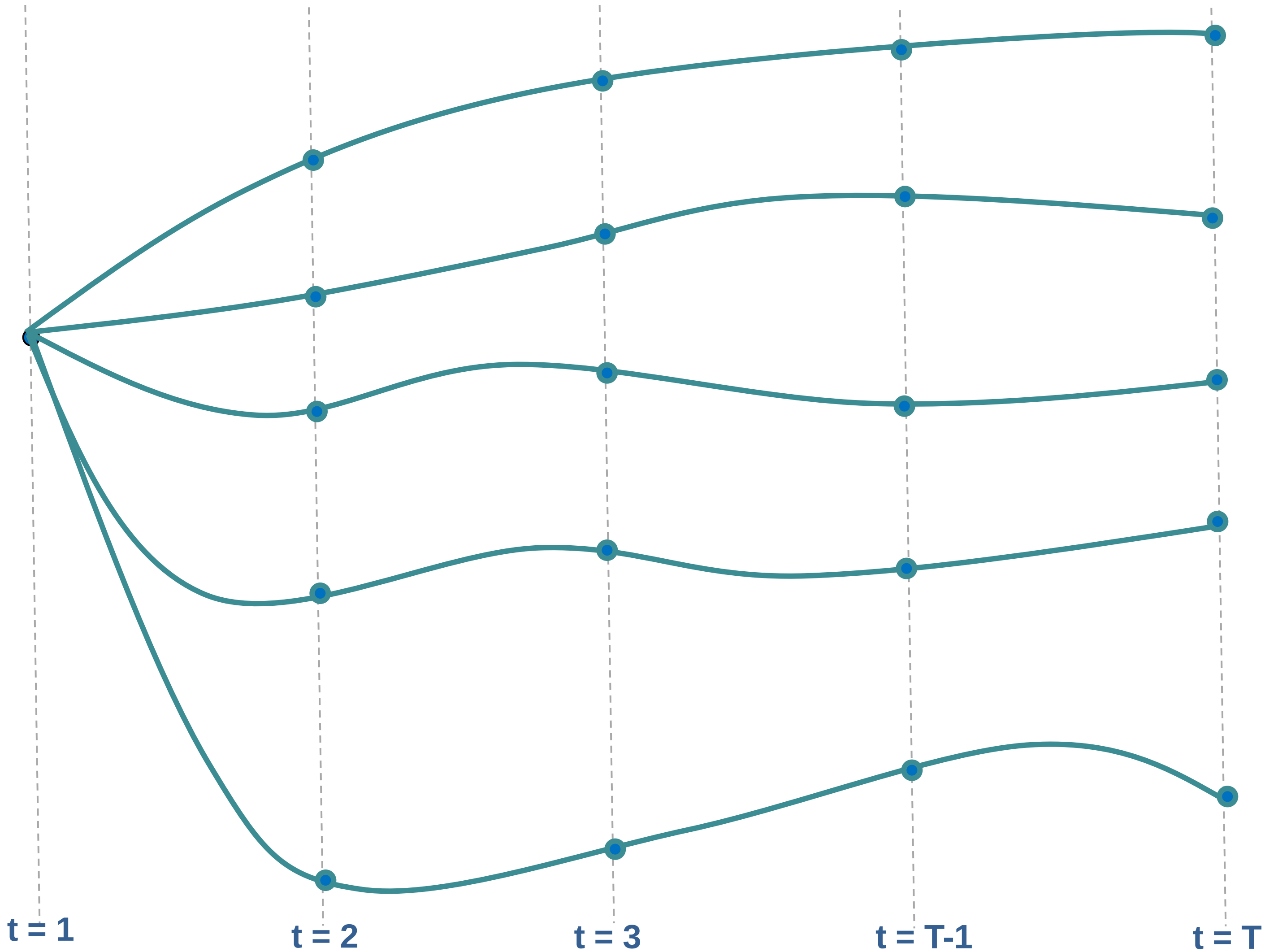
Objective function

The scheduling problem is solved by multistage stochastic decomposition, stochastic dual DP, where the original problem is decomposed in one-stage sub-problems

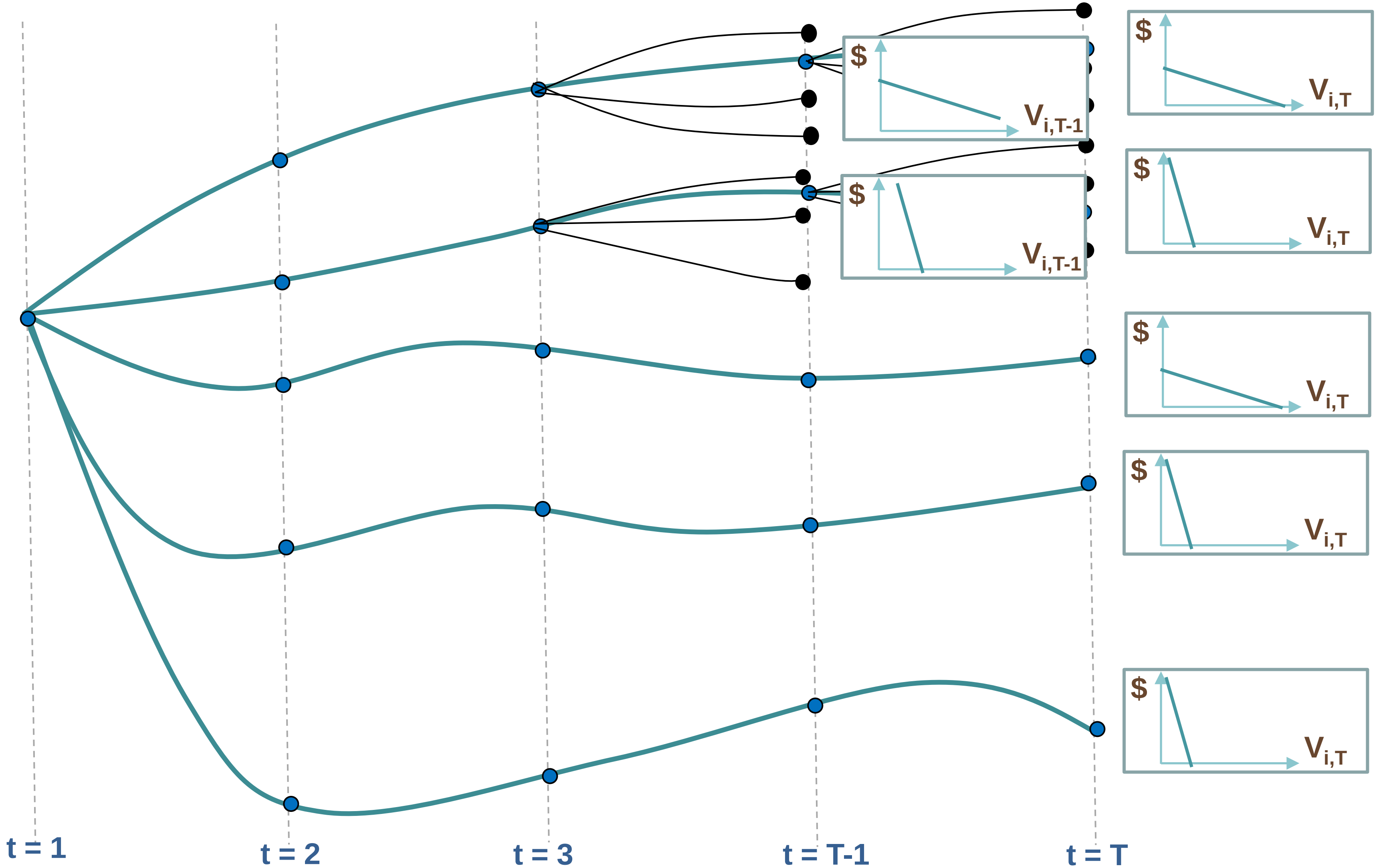
- Minimize present value of exp
  - Fuel costs + penalties for violation of operational constraints



SDDP solution algorithm: forward step



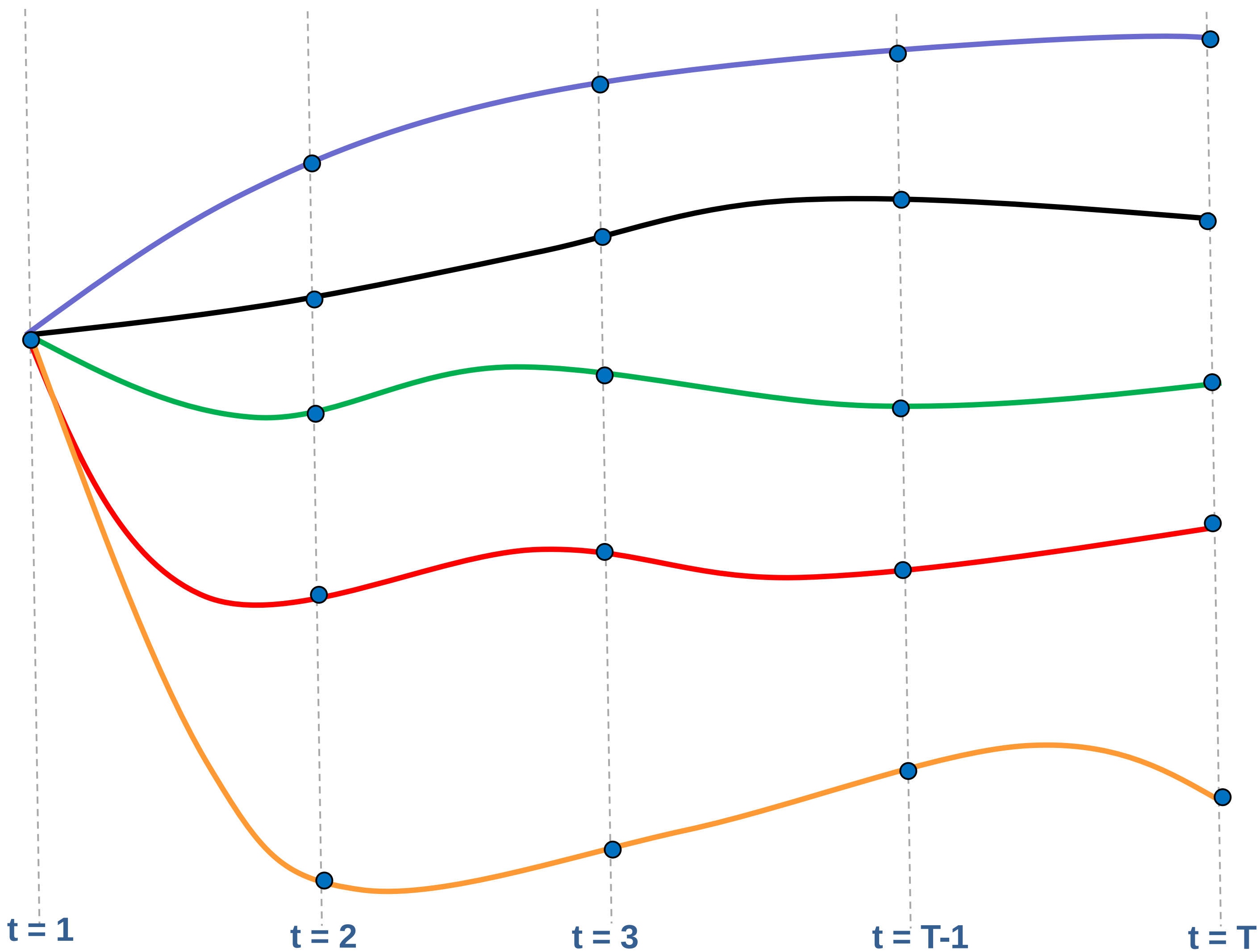
SDDP: backward step



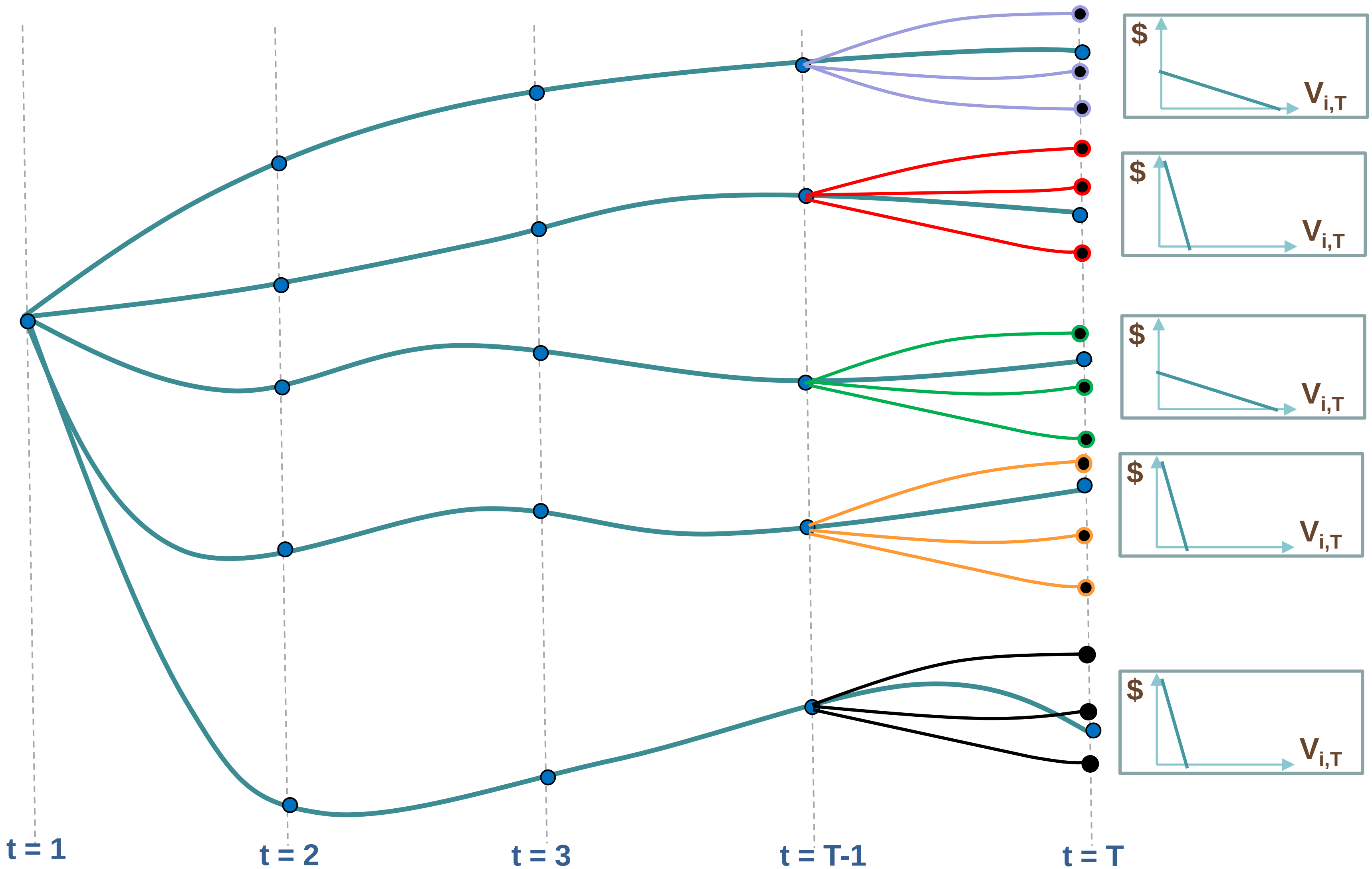
Decomposition and distributed processing

- The one-stage sub-problems can be solved simultaneously, which allows the application of distributed processing
- SDDP has been running on computer networks since 2001
- In 2006, with the creation of Amazon Web Services (AWS), SDDP runs on our PSR Cloud
  - We currently have 500 virtual servers with 16 CPUs and 900 GPUs each

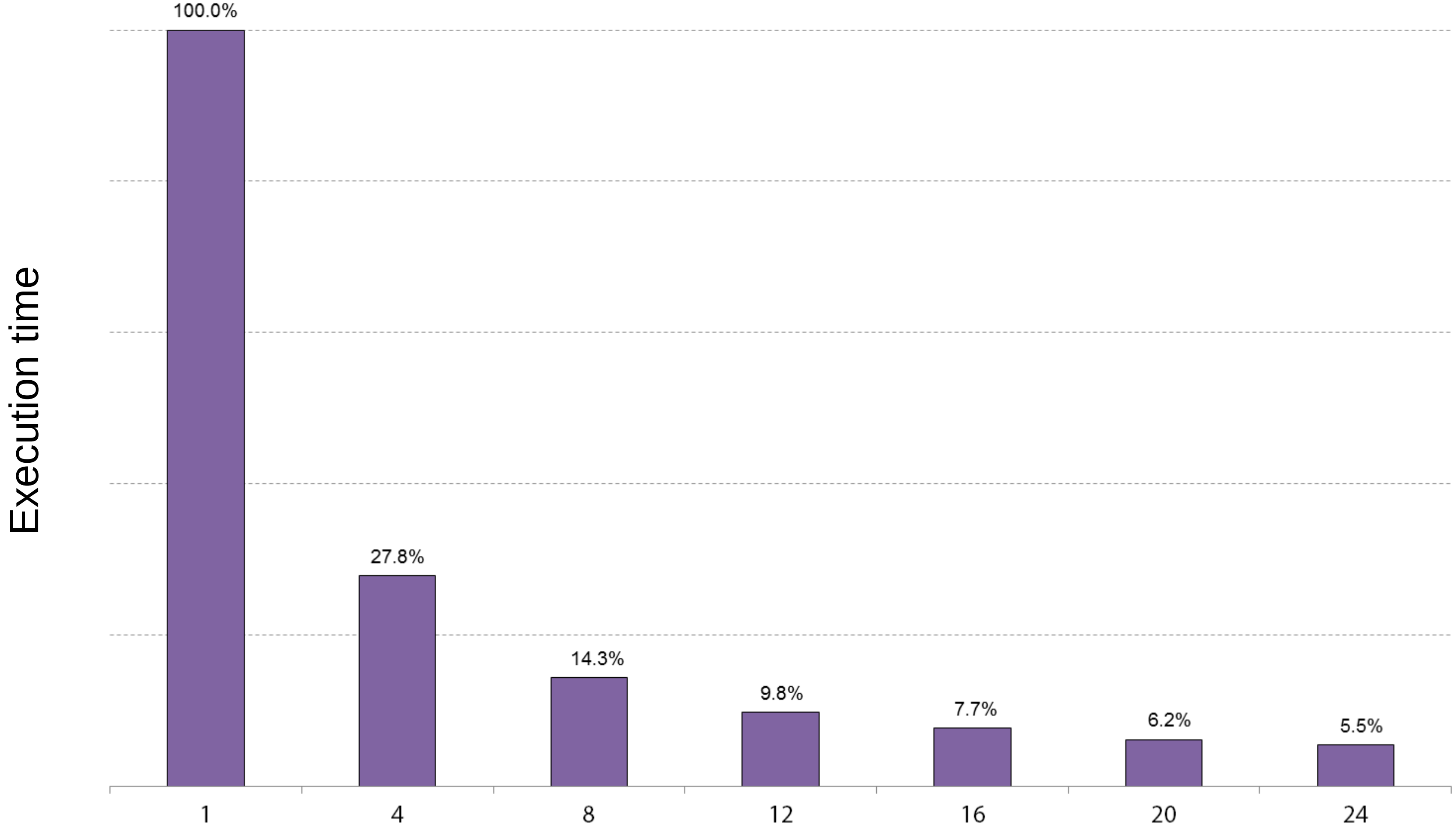
SDDP: distributed processing of forward step



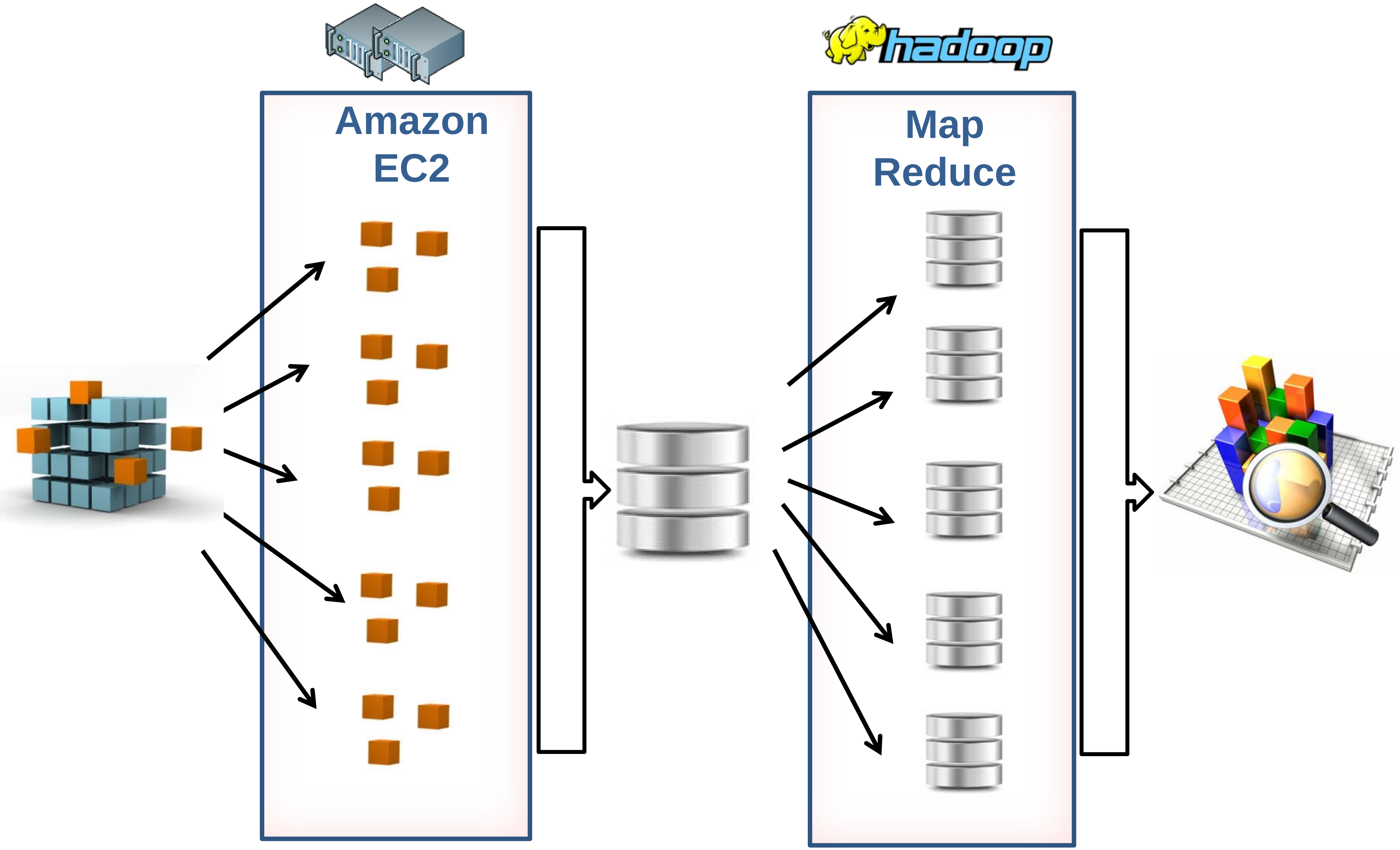
SDDP: distributed processing of backward step



Execution time vs. number of processes



Analysis of results with Big Data techniques

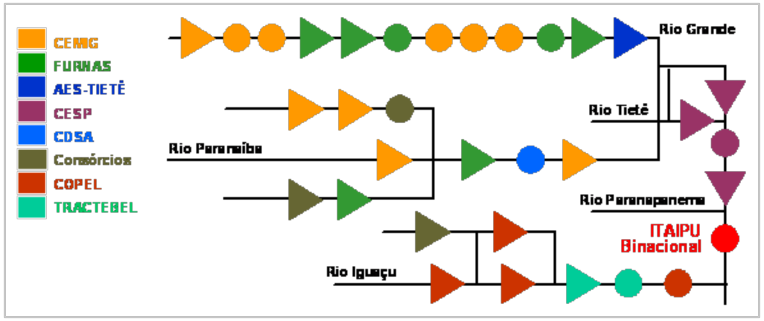


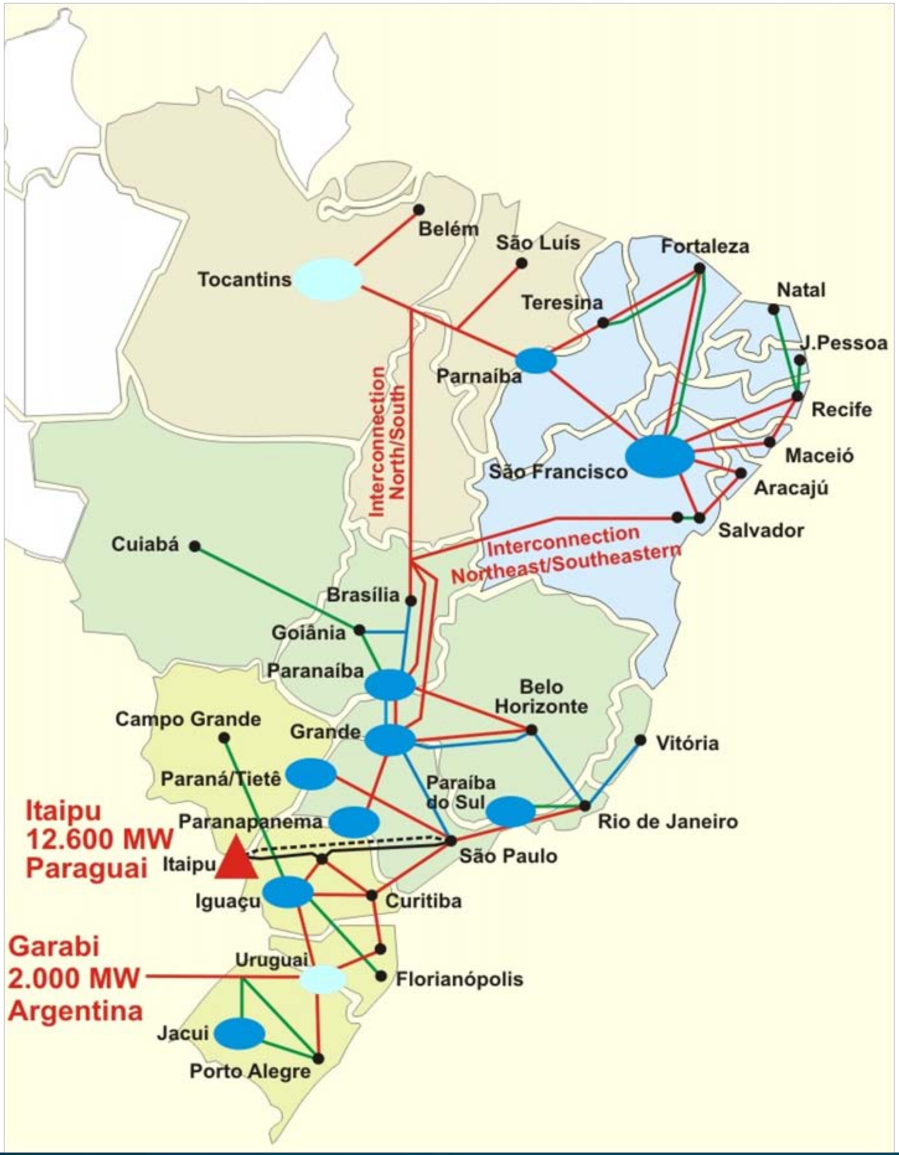
SDDP applications

- SDDP has been used in planning and operation studies of 70 countries in the Americas, Europe, Asia Pacific and Africa
  - Production simulation (distribution of spot prices, fuel consumption, power flows, emission etc.)
  - Integrated resource planning (generation, transmission and gas networks) (with other models: Optgen and Optnet)
  - Calculation of grid tariffs
  - System dispatch (ISO)

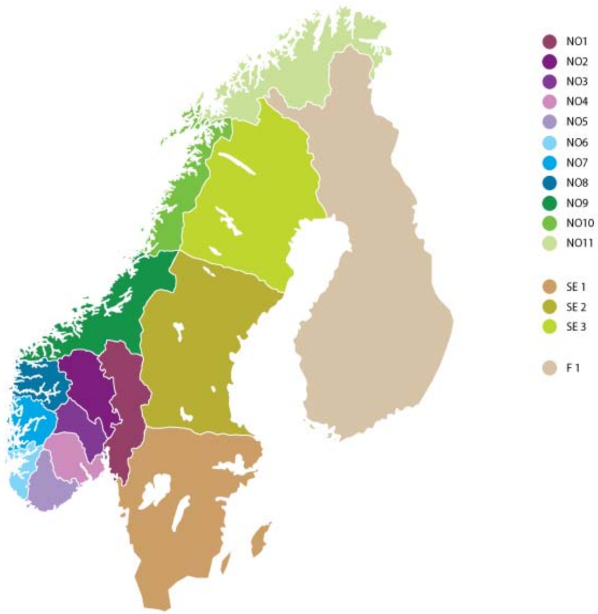
Example: Brazilian system

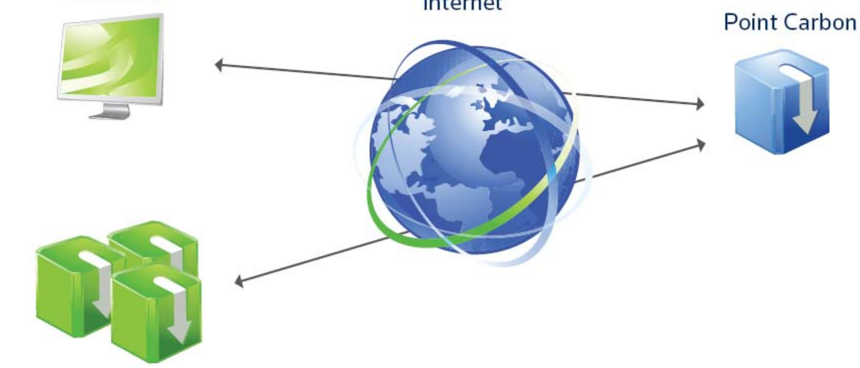
- Same area as continental US + ½ Alaska
- 120 GW installed capacity
- 85% hydro (remaining 15% include wind, gas, nuclear, coal and biomass)
- Main HV transmission network: 5,000 buses, 7,000 circuits





Nordpool price forecasting





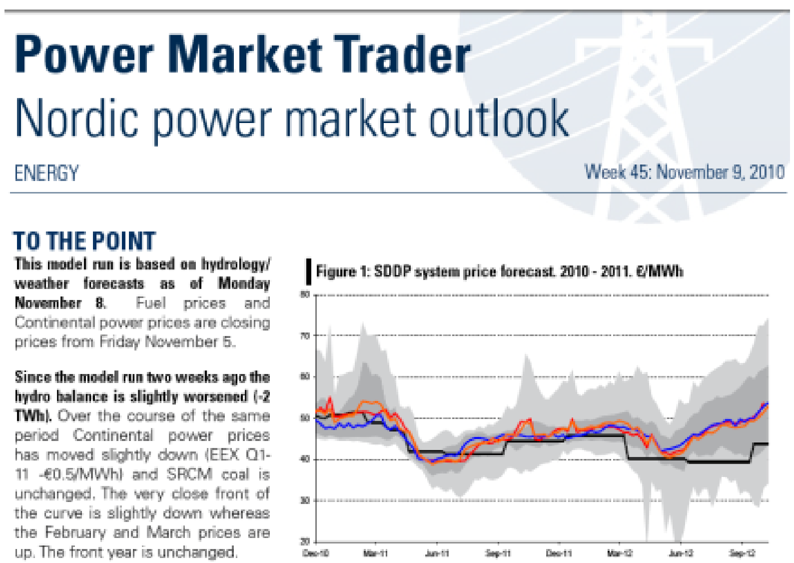
PointCarbon
A Thomson Reuters Company

THOMSON REUTERS

PSR

What can we offer?

- Detailed SDDP model output from Point Carbon's weekly model run
- Including price and inflow series both for the whole Nord Pool area and for specific price areas
- Point Carbon analysts as discussion partners
- Defining alternative scenarios
- Discussing results
- The model output versus the market
- 24/7 access to the SDDP model via SDDP Interactive
- Data base access to your previous model runs, exclusively available for your company
- In house training of SDDP Interactive
- Tailor made solutions



Power Market Trader

Nordic power market outlook

ENERGY

Week 45: November 9, 2010

TO THE POINT

This model run is based on hydrology/weather forecasts as of Monday November 8. Fuel prices and Continental power prices are closing prices from Friday November 5.

Since the model run two weeks ago the hydro balance is slightly worsened (-2 TWh). Over the course of the same period Continental power prices has moved slightly down (EEX Q1-11 -€0.5/MWh) and SRCM coal is unchanged. The very close front of the curve is slightly down whereas the February and March prices are up. The front year is unchanged.

Figure 1: SDDP system price forecast. 2010 - 2011. €/MWh

NCP: short-term scheduling

- Horizon: up to 4 weeks ahead
  - Time steps: 15min, 30min or 1 hour
- Formulated as a MIP
- Used by ISOs and utilities in Europe, Asia and Latin America
- Integration with SDDP
  - End of week target storage of hydro plants, energy target or FCF (water values);
  - NCP “details” SDDP mid- or long-term studies: boundary conditions applied to all stages and hydrological scenarios
    - Suitable for Cloud computing
    - Results: 8,760h x years x scenarios

NCP: modeling features

- Comprises SDDP modeling features + additional short-term capabilities such as more detailed unit commitment constraints (minimum up and down times, ramp rates etc.) and the following hydro features:
- Water routing times and wave propagation
- Ramping constraints on forebay and tailwater elevations and outflows
- Downstream encroachment on upstream plants
- Minimum spillage as fraction of inflow (biological opinion constraints related to nitrogen concentration levels that impact fish life)
- Maximum spillage as function of forebay elevation (water pressure)

NCP example: PNW peaking capability (PC)

- Measures sustained production capacity for a given number of hours and reliability level
  - PC is constrained both by the available capacity and the hydro energy available for peak shaving the demand; requires a detailed representation of hydro production
  - Renewables (wind farms, small hydro and solar) and operational rules, including those related to environmental constraints, represented

PC calculation for the PNW

- Challenge: model all sources of uncertainty (equipment availability, hydrology and unconventional renewables)
- PNW database and modeling
  - Model of the PNW by Balancing Areas (by Mike McCoy)
    - Thermal power data (variable cost, maximum generation, …)
    - Hydropower data (installed capacity, live storage, flow limits, …)
    - Demand profile (hourly values)
    - Historical water years file
  - NCP and converters (for data formats and physical units)

PC formulation

Max λ

Subject to:

$\Sigma_i\, g(i,t) > \lambda\, D(t)$ for all t =1,2,…T

+ all mentioned hydro operational constraints

+ constraints on $g(i,t)$ and $\Sigma_t\, g(i,t)$ (boundary conditions)

Where

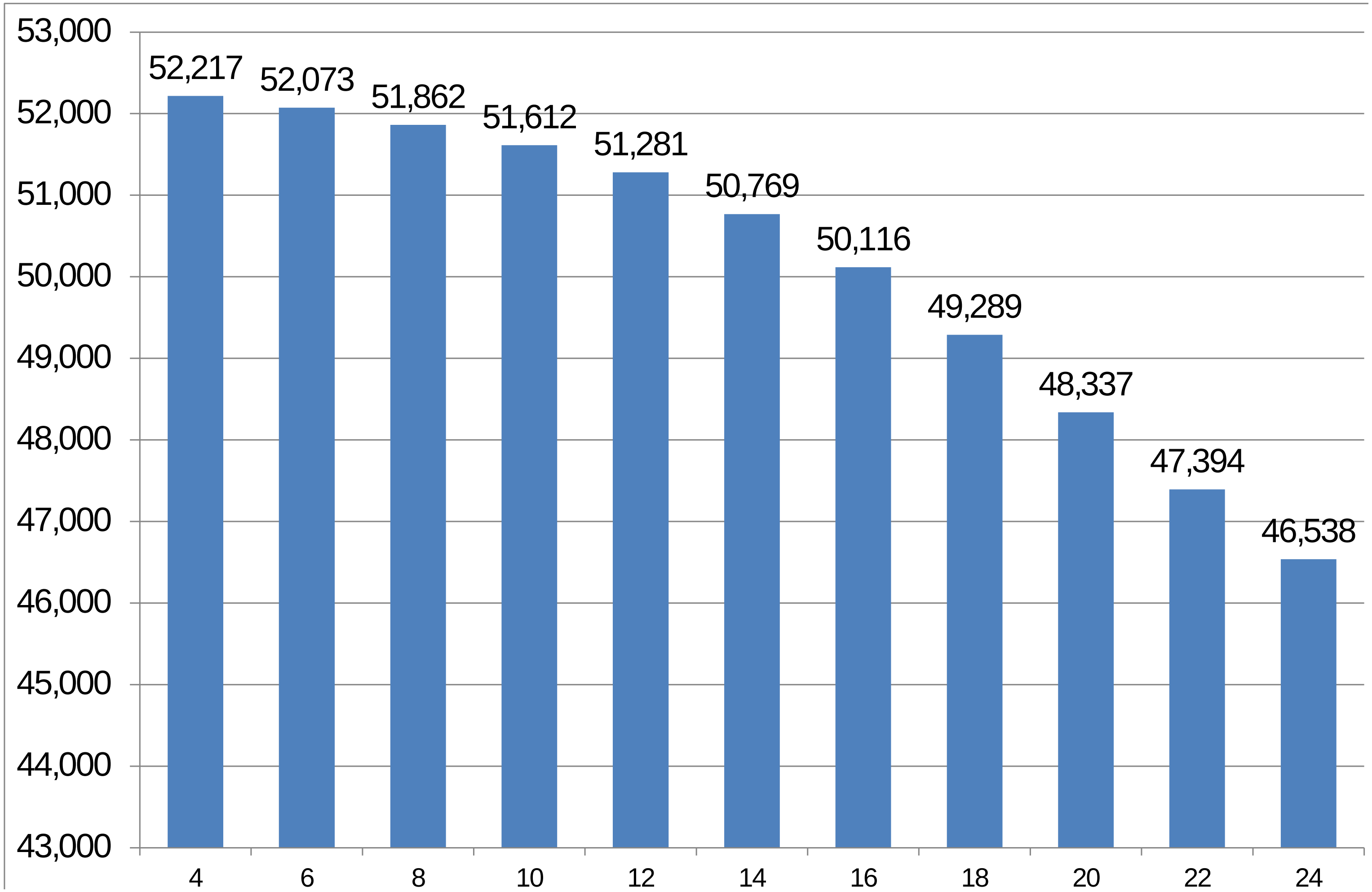
$D(t)$	hourly demand
$g(i,t)$	production of plant i in hour t
T	number of hours in a stage m

PC calculation procedure

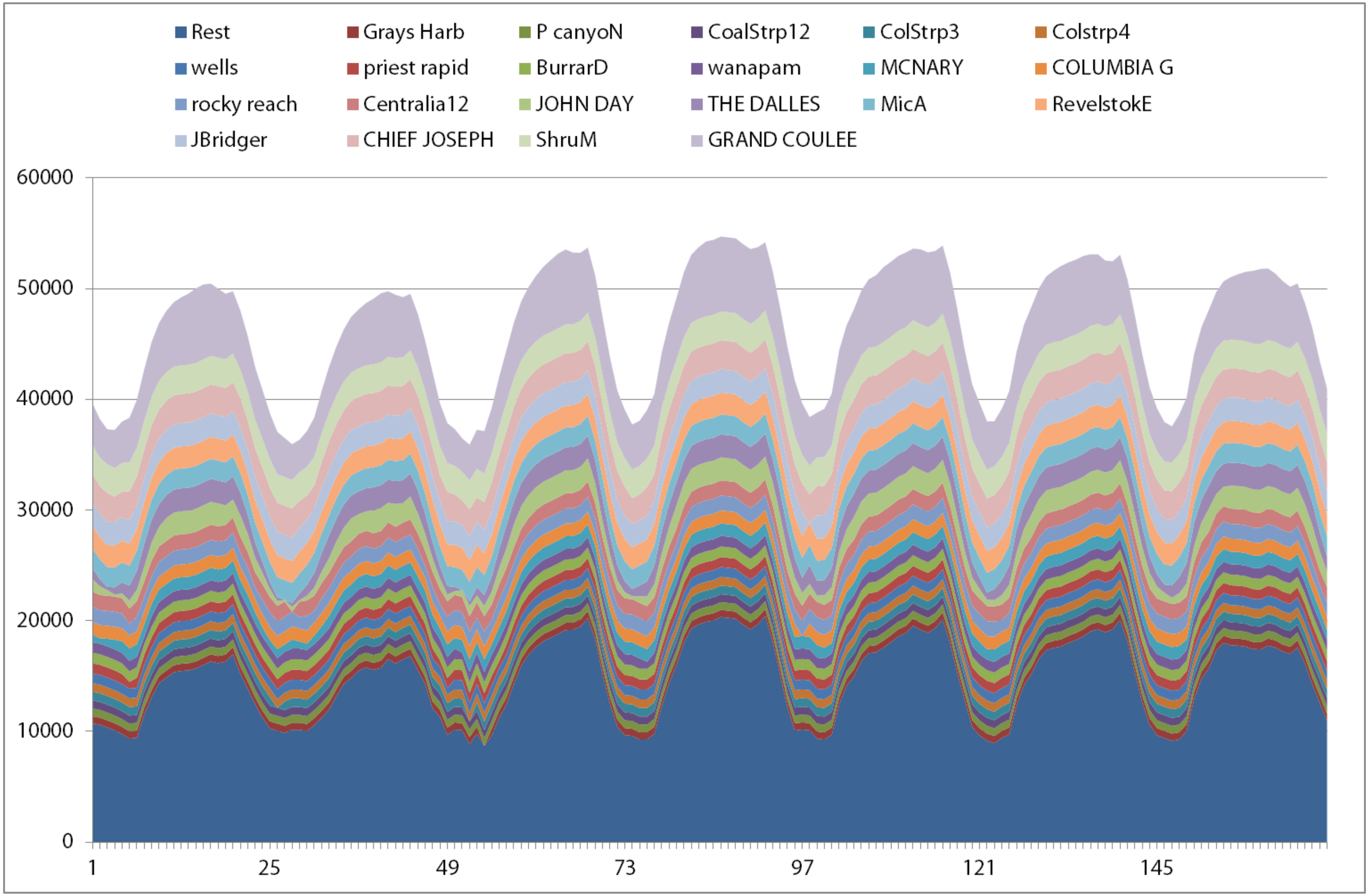
- For each hydrological year *y* and stage *m* we retrieve results from the SDDP mid-term planning (initial & final storage levels for each reservoirs or hydro plants' production for that stage)
  - NCP solves a problem with results from SDDP as boundary conditions and determine PC(*y*,*m*) (Peaking Capability)

PC results for one sub problem P(*y*,*m*)

Peaking Capability for a given number of hours t' for this week and hydrological scenario (mean value of top hours of each day)



PC example of results



PSR development team

Computational tools development

Name	Title	Area
Nora Campodónico	DSc	SE
Rafael Kelman	DSc	SE
Raphael Chabar	DSc	SE
Luiz Mauricio Thome	MSc	EE
Silvio Binato	DSc	SE
Maria de Lujan Latorre	DSc	SE
Fernanda Thome	MSc*	SE
Luiz Carlos Costa Jr	MSc*	SE
André Dias	MSc	SE
Gerson Oliveira	DSc	SE
Julio Alberto Dias	MSc*	SE

SE : Systems Engineering
EE : Electrical Engineering
CS: Computer Science

* DSc in 2012

IT and Cloud Computing

Name	Title	Area
Fabiano Oliveira	DSc	SE
Marcelo Cruz	BSc	CS
Julio Cahuano	DSc	SE
Gustavo Voll BSc CC	BSc	CS
André Granville	MBA	SE
Fabrício Silva	BSc	CS

PSR

THANK YOU

www.psr-inc.com

psr@psr-inc.com

+55 21 3906-2100

+55 21 3906-2121