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Probabilistic Forecasting, Stochastic Optimization, & The Progressive Hedging Algorithm

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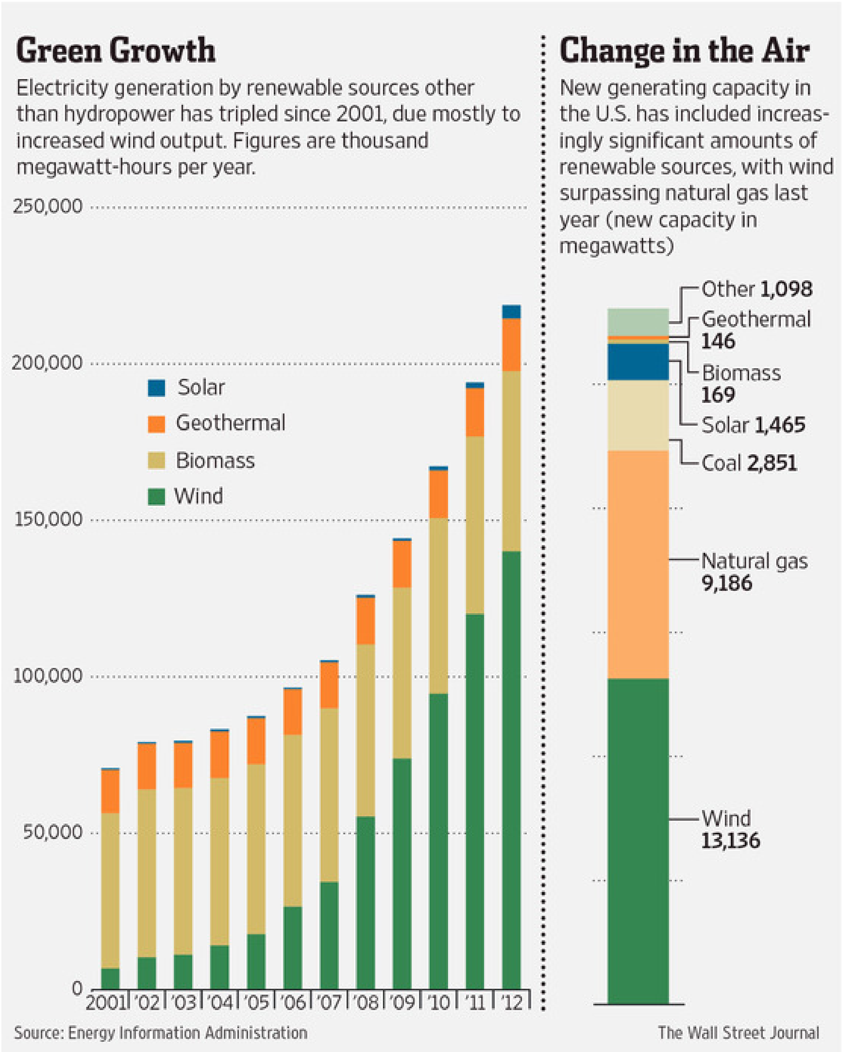
Growth of Renewables



Challenges

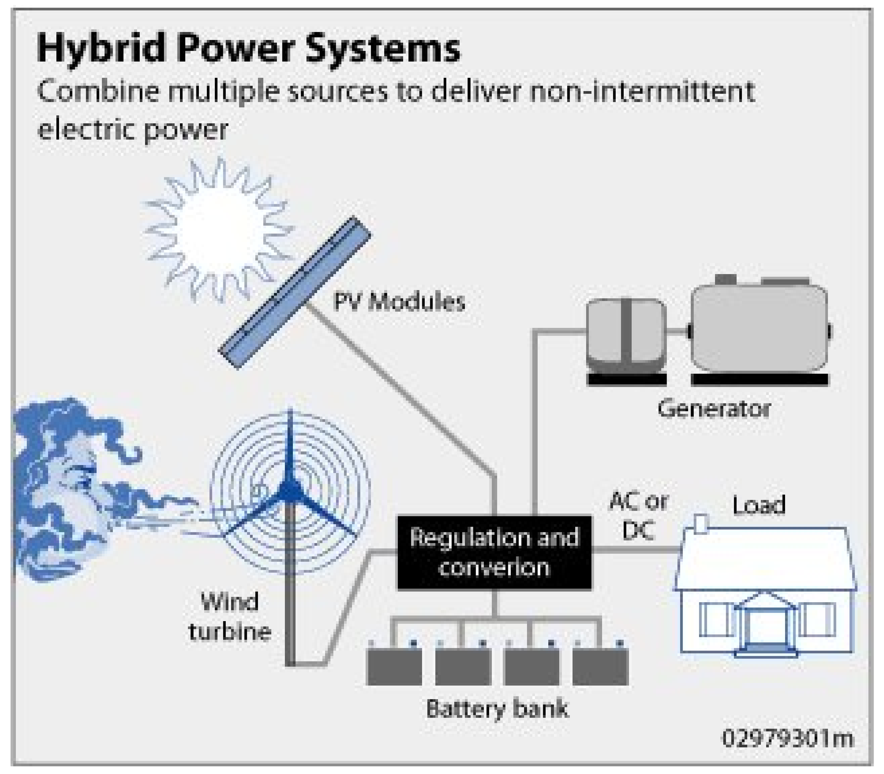


Figure 2: http://oneinabillionblog.com

- Variability of renewable energy sources
- Solar and wind forecasting
- Integration costs
- Creating dispatchable power sources
- and more...

Contact Information

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Uncertainty in Wind Power

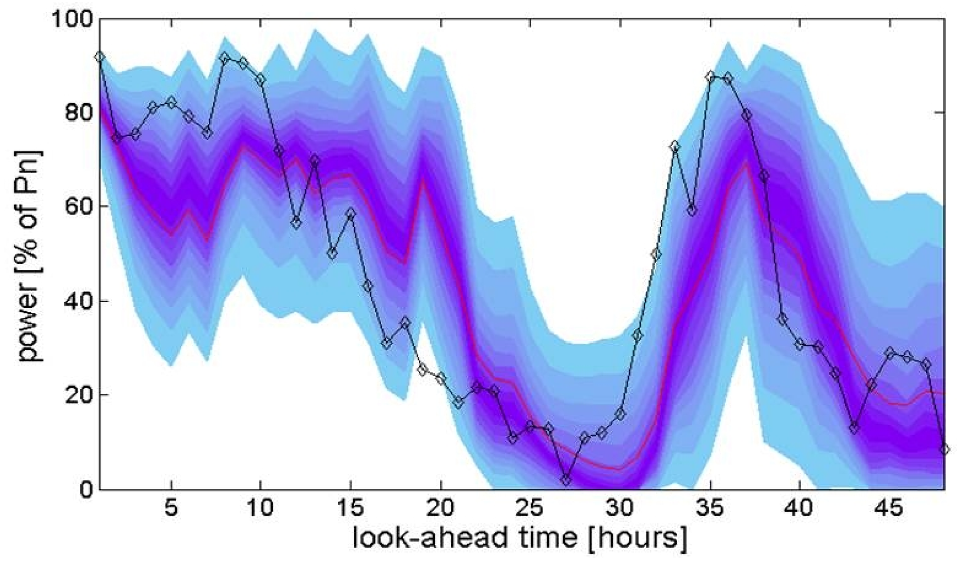

Figure 1: www.ewea.org

- Forecasting wind power is challenging
- Typically done using $ARMA$ models, or from wind speed forecasts mapped to power
- Data science critical to stochastic optimization!

Stochastic Unit Commitment

A general stochastic optimization model:

$$\begin{aligned} \min \quad & cx + \mathbb{E}[f(x,\omega)] \\ \text{s.t.} \quad & Ax \geq b, x \in X, \\ f(x,\omega) = \quad & \min q^{\omega} y^{\omega} \\ & \text{s.t.} By^{\omega} \geq d^{\omega} - C^{\omega} x \end{aligned}$$

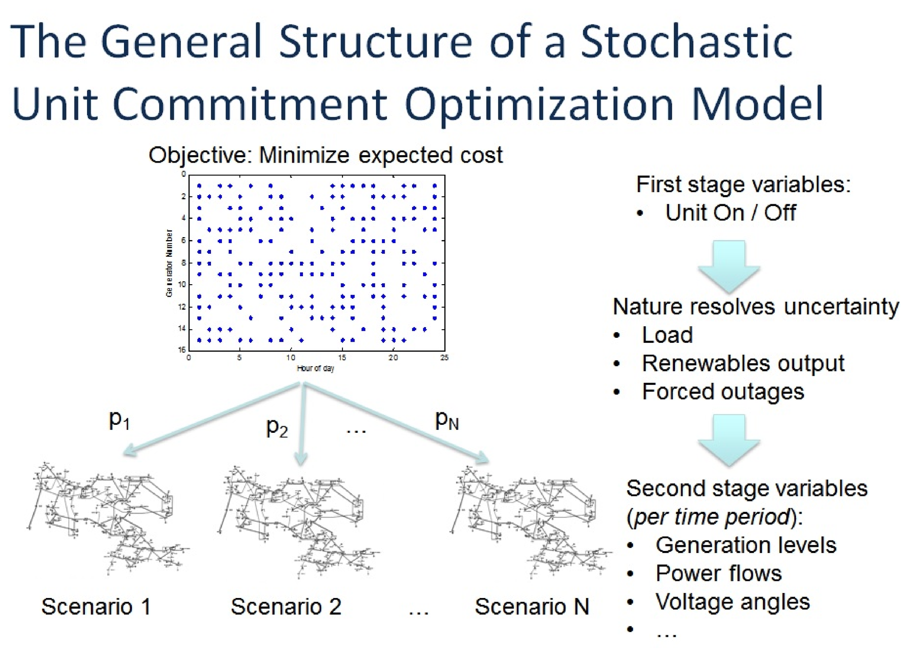

Figure 3: *On Deployment Barriers & Research Challenges for Stochastic Unit Commitment, Jean-Paul Watson*

- Usually requires discrete distributions of scenarios
- Large number of scenarios requires specialized algorithms to decompose the problem
- Numerous applications in renewable energy operations and planning

Solving scenario problems, given an x, may be easy...

Progressive Hedging Algorithm

One example of such a decomposition algorithm is the Progressive Hedging Algorithm (Rockafellar and Wets (1991)):

1: **initialize:**
   $k := 1, \overline{z}^1 := +\infty,$
   $(x_s^1, y_s^1) := \text{argmin}_{x,y_s}[(cx + fy_s) : x, y_s \in Q_s], \forall s \in S,$
   $\overline{x}^1 := \sum_{s \in S} p_s x_s^1$
2: $k := k + 1$
3: **for** $s \in S$ **do:** $(x_s^k, y_s^k) = \text{argmin}_{x,y_s}[(cx + fy_s + w_s^{k-1}x + \rho\|x - \overline{x}^{k-1}\|) : x, y_s \in Q_s]$
4: $\overline{x}^k := \sum_{s \in S} p_s x_s^k$
5: $w_s^k = w_s^{k-1} + \rho(x_s^k - \overline{x}^k)$
6: **if** $\|x_s^k - \overline{x}^k\| < \epsilon$ **then** terminate, else go to Step 2.

Steps 1 & 3 can be implemented in parallel.

Recent Advances

Issues:

- Mixed integer programs may induce cycling
- Values of ρ influence convergence
- Large number of iterations may be required for convergence

$\Longrightarrow$ See Watson, Woodruff (2011)

Advances:

- Parallel implementation of Step 3
  $\Longrightarrow$ Ryan et al. (2013)
- Values of ρ influence convergence
  $\Longrightarrow$ Watson, Woodruff (2011)

Some applications:

- Transportation network protection
  $\Longrightarrow$ Fan, Liu (2008)
- Stochastic inventory routing
  $\Longrightarrow$ Hvattum, Løkketangen (2008)
- Hydrothermal planning
  $\Longrightarrow$ Santos et al. (2009)
- Power system optimization
  $\Longrightarrow$ Takriti et al. (1995)
- Stochastic unit committment
  $\Longrightarrow$ Ryan et al. (2013)

Ongoing Research

We are working on subsequent improvements of the Progressive Hedging algorithm:

- How do solutions of one scenario problem influence the others?
- How to pass feasibility/optimality cuts from one scenario problem to another?

We are working on applications of the Progressive Hedging algorithm on electric grid models, with a goal of putting into practice:

- Model and data-based probabilistic forecasting
- Stochastic operations models.

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