Eurotranselec: Integrating financial constraints in systemic studies of the energy transition with minimal assumptions

Laurent Pagnier, HES-SO, School of Engineering

February 7, 2017

Energy transition

European Union: 20/20/20.
Higher penetration of renewable energy sources (RES).
Requirements:

- Flexible sources.
- Energy storage.

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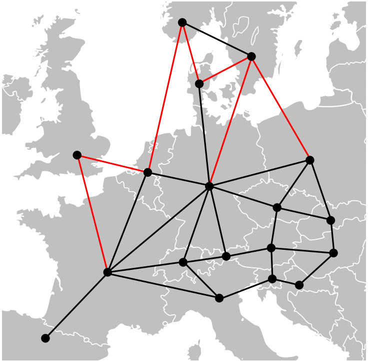
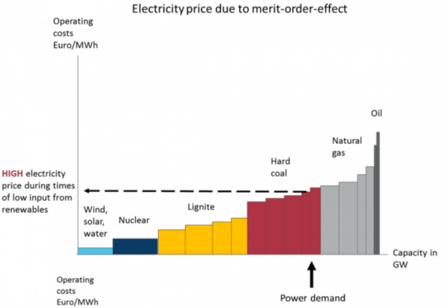
Are dam and pumped storage power plants correctly rewarded?

Future pan-European power dispatch

Aggregated model of European power grid.





$$W_i(t) = a_k P_{ki}(t) + b_k [P_{ki}(t)]^2 / P_{ki}^{\max}$$

Production profiles $\{P_{ki}(t)\}$ minimizing the annual generation cost

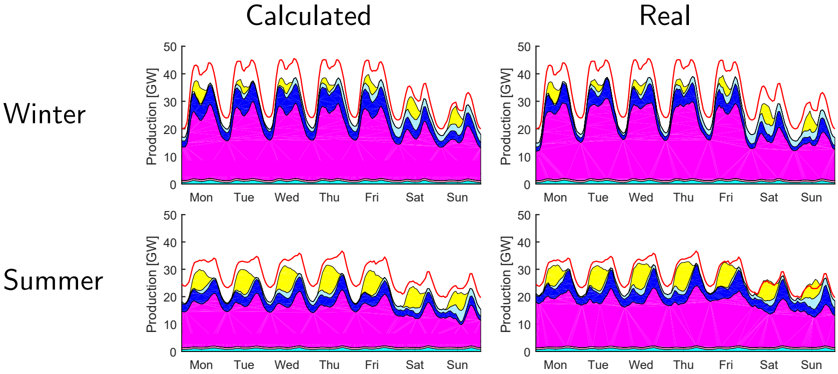
$$W(\{P_{ki}(t)\}) = \sum_{i,t} W_i(t)$$

Calibration and validation

Calibration: matching historical data.

$$W_i(t) = a_k P_{ki}(t) + b_k [P_{ki}(t)]^2 / P_{ki}^{\max}$$

Italian electricity production in 2015:



Wind, PV, Dam, Gas & Hard coal, RoR.

Effective electricity price

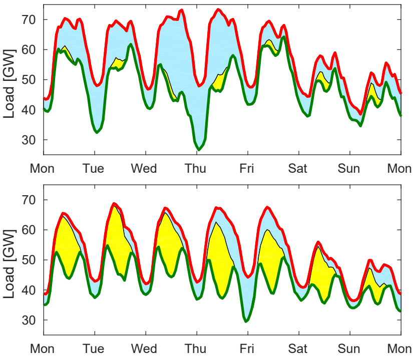
The residual load is defined as the load from which the non-flexible productions are subtracted.

$$L_R(t) = L(t) - P_{\mathrm{PV}}(t) - P_{\mathrm{WD}}(t) - P_{\mathrm{MR}}$$

Non-flexible productions:

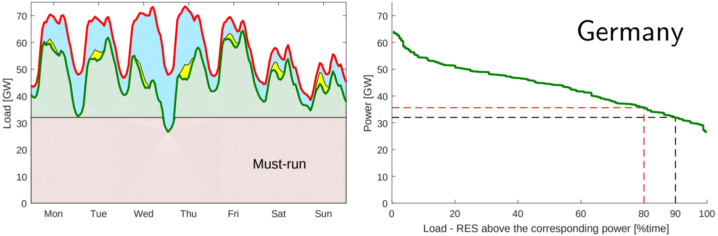
- Photovoltaics.
- Wind power.
- Must-run.

Residual load quantifies supply/demand.



Must-run power

Must-run power is due to plants agreeing to produce power below their cost price to avoid ramping cost.



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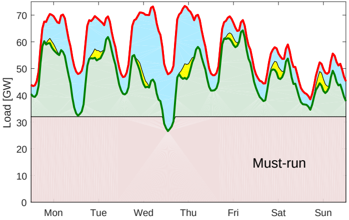

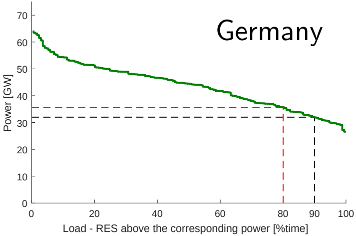

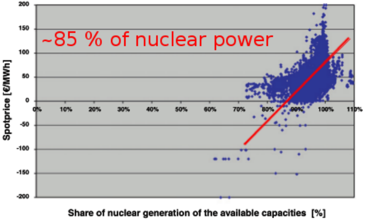

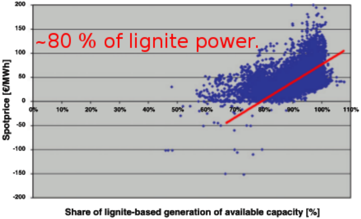

Nicolosi, Energy Policy (2010).

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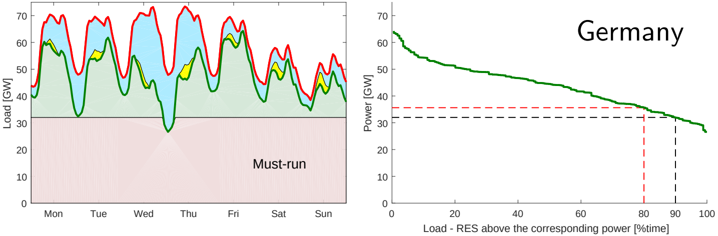
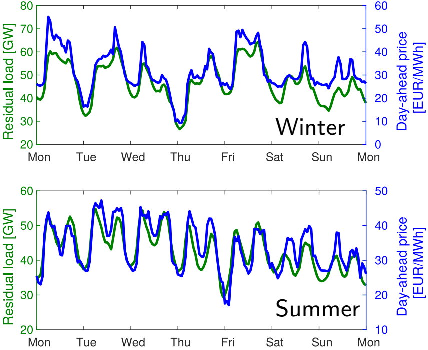


Must-run power (prior 2010): 30-35 GW.

Residual load and day-ahead electricity price

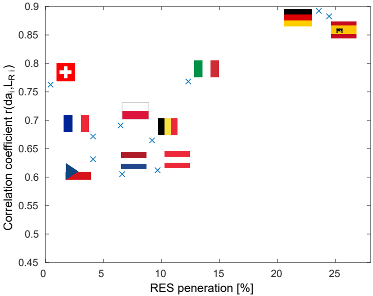
Germany:



Correlation coefficient:

$$r(x,y) = \frac{\sum_{k=1}^{n}(x(t_k)-\bar{x})(y(t_k)-\bar{y})}{\sqrt{\sum_{k=1}^{n}(x(t_k)-\bar{x})\sum_{k=1}^{n}(y(t_k)-\bar{y})}}$$

$$-1 \leq r(x,y) \leq 1$$



Electricity price based on residual load

$$\boxed{p_{\mathrm{da}}(t) = \Delta p_{\mathrm{da}} L_R(t) + p_{\mathrm{da}0}}$$

$$L_R(t) = L(t) - P_{\mathrm{PV}}(t) - P_{\mathrm{WD}}(t) - P_{\mathrm{MR}}$$

Fitting historical data:

$\Delta p_{\mathrm{da}} \approx 1$ [EUR/MWh·GW^{-1}]
$p_{\mathrm{da}0} \approx 20$ [EUR/MWh] for Germany.

Roughly constant over past few years.

Electricity price based on residual load

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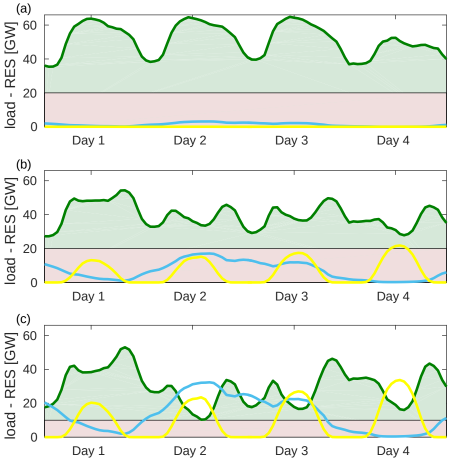

Old paradigm (< 2010).

Transition.

New paradigm (> 2020).

Application 1: Income of a pumped-storage plant

Income:

$$\$ = \int p_{\mathrm{da}}(t) P_{\mathrm{PS}}(t) \mathrm{d}t$$

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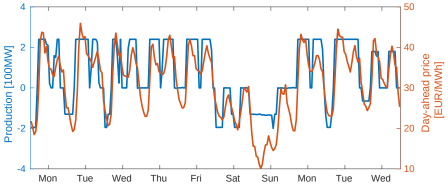
Historical production of FMHL plant:



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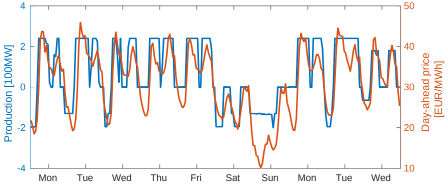

$$\boxed{\max \$ \propto {\rm Var}[L_R]}$$

$$p_{\rm da}(t) = \Delta p_{\rm da} L_R(t) + p_{\rm da0}$$

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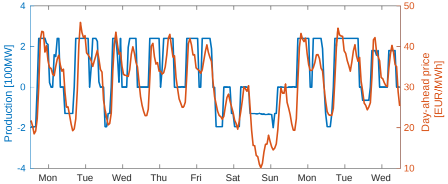
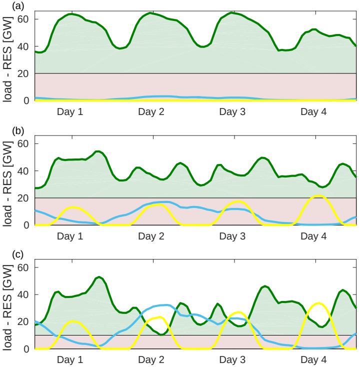
Income $\searrow \nearrow$.





Application 1: Income of a pumped-storage plant

Numerical optimization:

$$\$ = \max \int p_{\mathrm{da}}(t) P_{\mathrm{PS}}(t) \mathrm{d}t$$

Constraints:

- Limited Storage.
- Max power.

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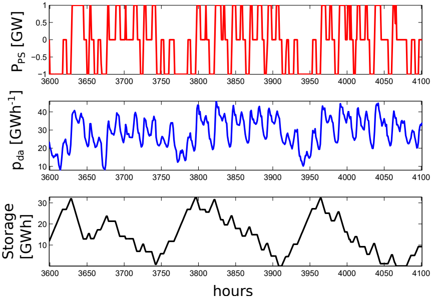

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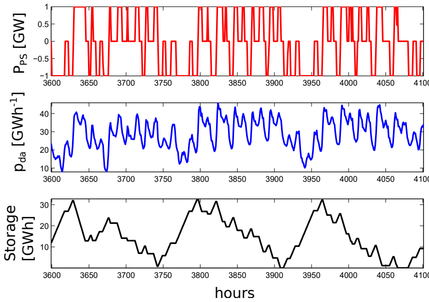
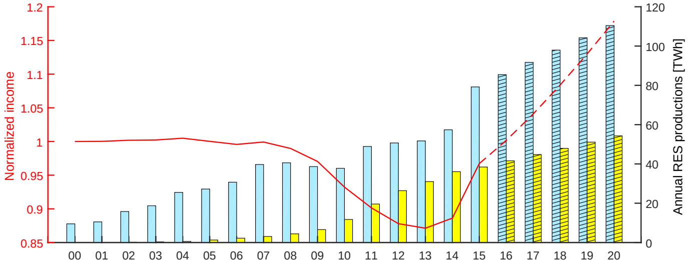




Application 2: Profitability of dam hydroelectricity

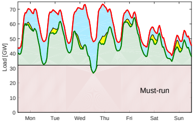
Numerical optimization:

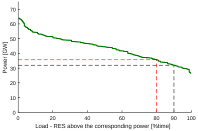
$$\$ = \max \int p_{\mathrm{da}}(t) P_{\mathrm{D}}(t) \mathrm{d}t$$

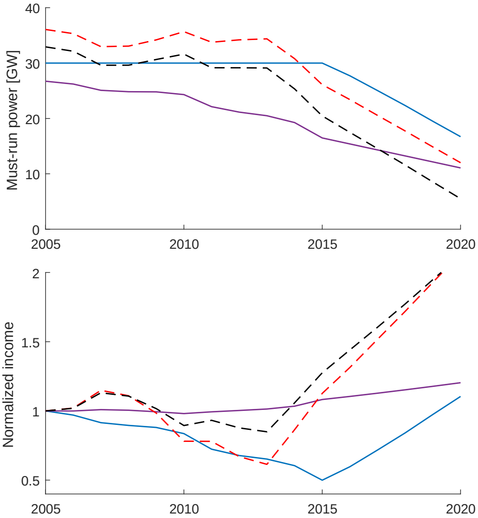
Additional constraint:

$$\int P_{\mathrm{D}}(t) \mathrm{d}t = \int I(t) \mathrm{d}t$$

As long as possible.
Exact compensation.
must-run 8000h.
must-run 7000h.







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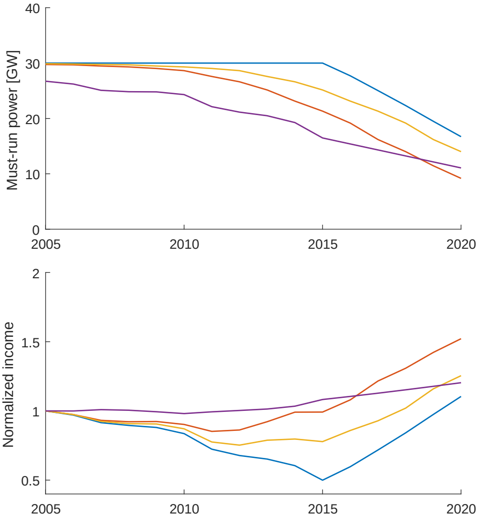
As long as possible.
Exact compensation.
Expectation.
Slightly anticipated.



Conclusion

We developed a pan-European power dispatch:

- Future usage of flexible sources.

We derived an electricity price based on residual load:

- Study profitability of the different production types.

Better profitability sooner if energy transition proceeds faster:

- Flexibility will be properly rewarded if overcapacity is reduced.