The energy transition in the electric sector : two (almost randomly) chosen challenges

Philippe Jacquod

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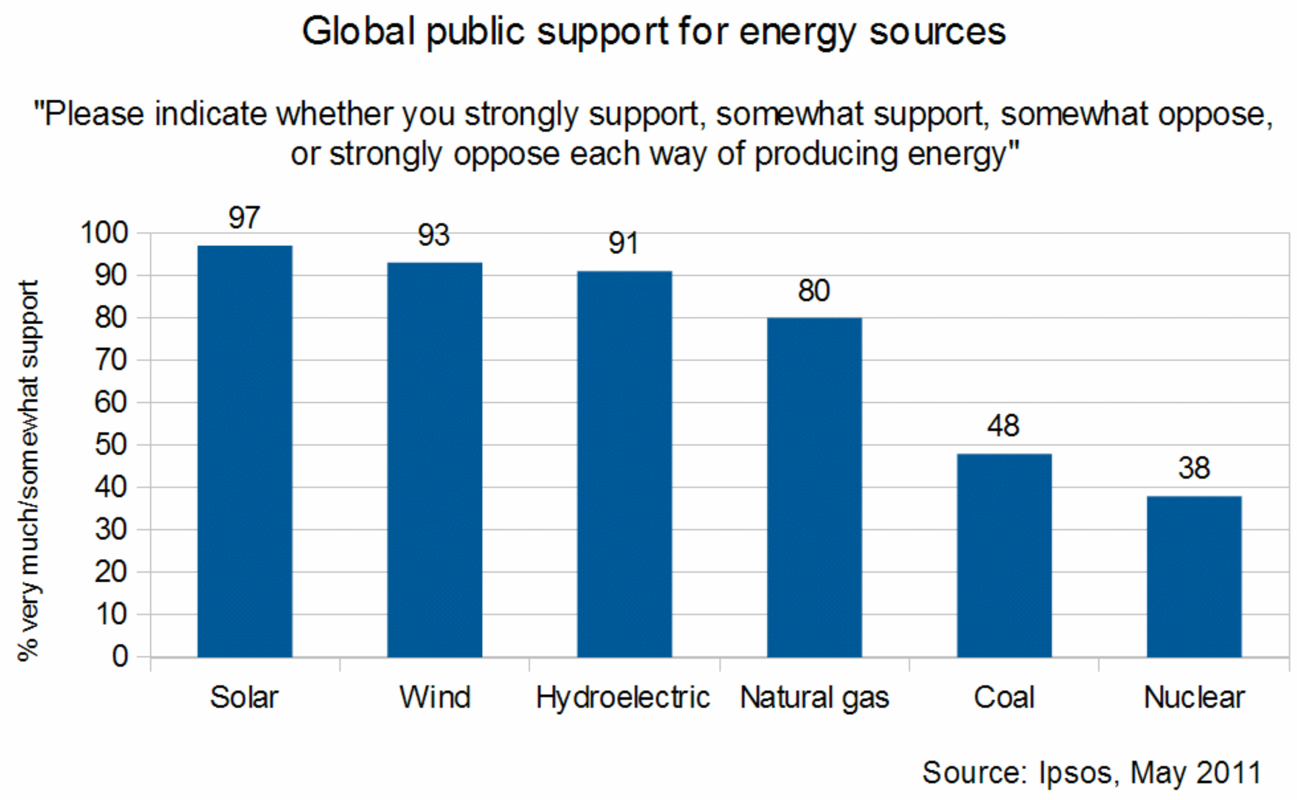
Goals of the energy transition

*to meet energy demand from human activities solely with renewable sources
*committed in particular to reducing emission of greenhouse gases (CO_2 etc.)

"Renewable energy : energy that is collected from resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat." -wikipedia



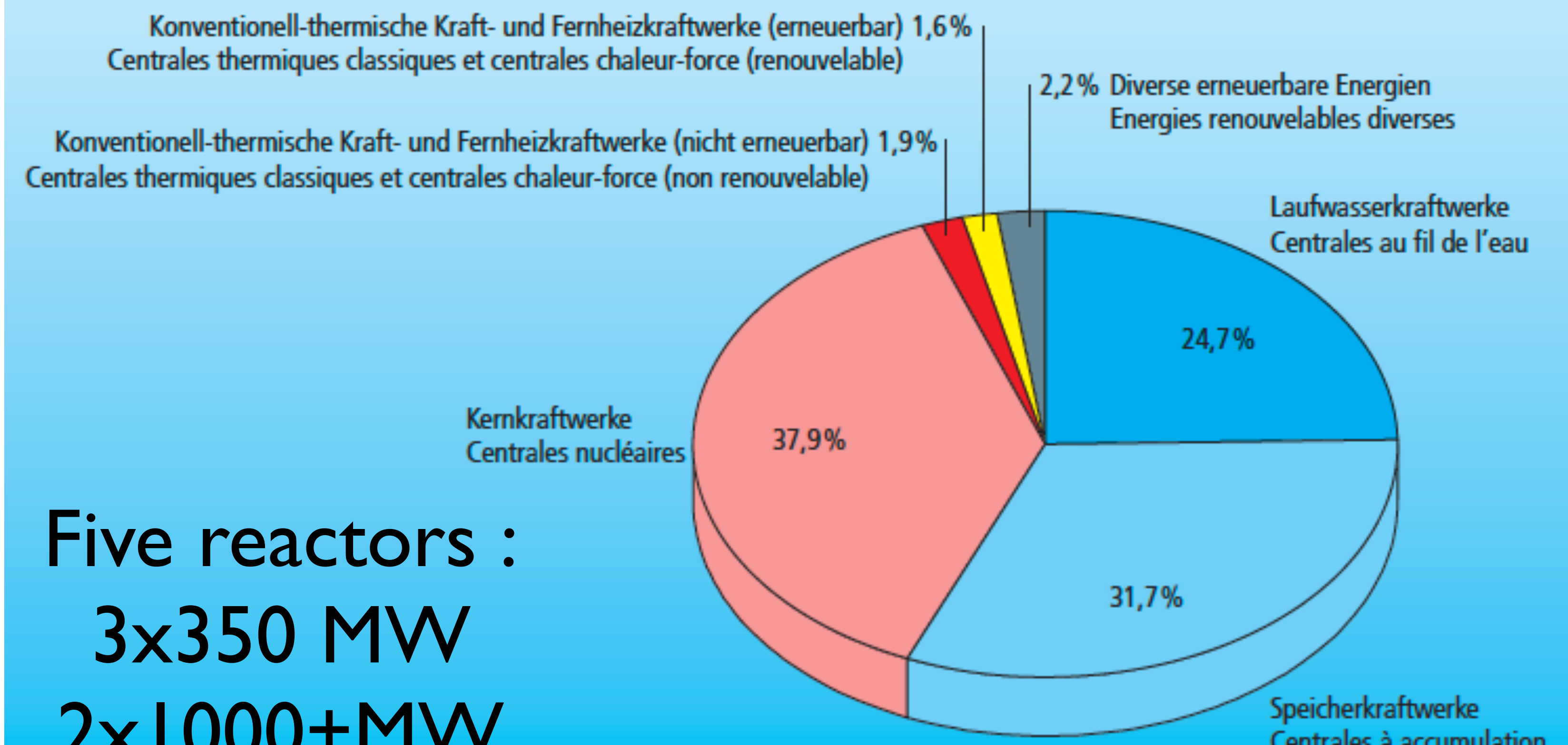
19000 people in 24 countries
March 2011 : Fukushima

The energy transition : the swiss case

Phase out nuclear power plants

\+ Reduction of greenhouse gas emissions

= Increased penetration of renewables



Five reactors :
3x350 MW
2x1000+MW

The energy transition : the swiss case

" Why phase out nuclear power plants in Switzerland ?
Is there a risk of a tsunami in Switzerland ? "

"No. But…"

After the decommissioning of Oldbury Nuclear Power Station's Reactor 1 on 29 February 2012, Beznau 1 is the oldest operating nuclear power station in the world.

The energy transition : the swiss case

" Why phase out nuclear power plants in Switzerland ?
They are cheap to run and produce cheap electric power."
...
"Really ?"

Tabelle Z-1: ***Kostenannahmen für ein neues Kernkraftwerk***

	Einheit	Referenz	Bandbreite	Bemerkung:
Typ	-	EPR / PWR	-	Druckwasser
Leistung	MW_{el}	1'000-1'600	-	
Lebensdauer	a	60		
Volllaststunden	h/a	7'600	7'400 - 8'000	
Gesamtwirtschaftlicher Zinssatz	%	2.5	-	
Gesamtwirtschaftliche Abschreibungsdauer [a)]	a	60	-	
Betriebswirtschaftlicher Zinssatz	%	Eigenkapital: 9 Fremdkapital: 6		
Betriebswirtschaftliche Abschreibungsdauer	a	30	20 - 40	
Investitionskosten	CHF_{2009}/kW_{el}	4'250-5'250	3'500 - 6'000	
Betriebskosten	$CHF_{2009}/kW_{el}/a$	165	120 - 190	Inkl. Nachrüstung
Stilllegungskosten	CHF_{2009}/kW_{el}	750	350 - 1'100	
Brennstoffkosten (vollständiger Brenn-stoffzyklus)	CHF_{2009}/MWh_{el}	16	12 - 18	Ohne Wiederauf-bereitung

a) Bei der hier verwendeten gesamtwirtschaftlichen Betrachtung ist die Abschreibungsdauer mit der technischen Lebensdauer bzw. Laufzeit identisch

Prognos 2011

~6ct/kWh

Sources : "Kosten neuer Kernkraftwerke", Prognos Report, F Hess, A Kirchner, V Rits (Feb. 2011)

The energy transition : the swiss case

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Prognos 2011

at least
8-9ct/kWh

Leibstadt power plant constructed for that price in 1980's !

Sources : "Kosten neuer Kernkraftwerke", Prognos Report, F Hess, A Kirchner, V Rits (Feb. 2011)

The energy transition

" Why phase out nuclear power plants in Switzerland ?
They are cheap to run and produce cheap electric power."
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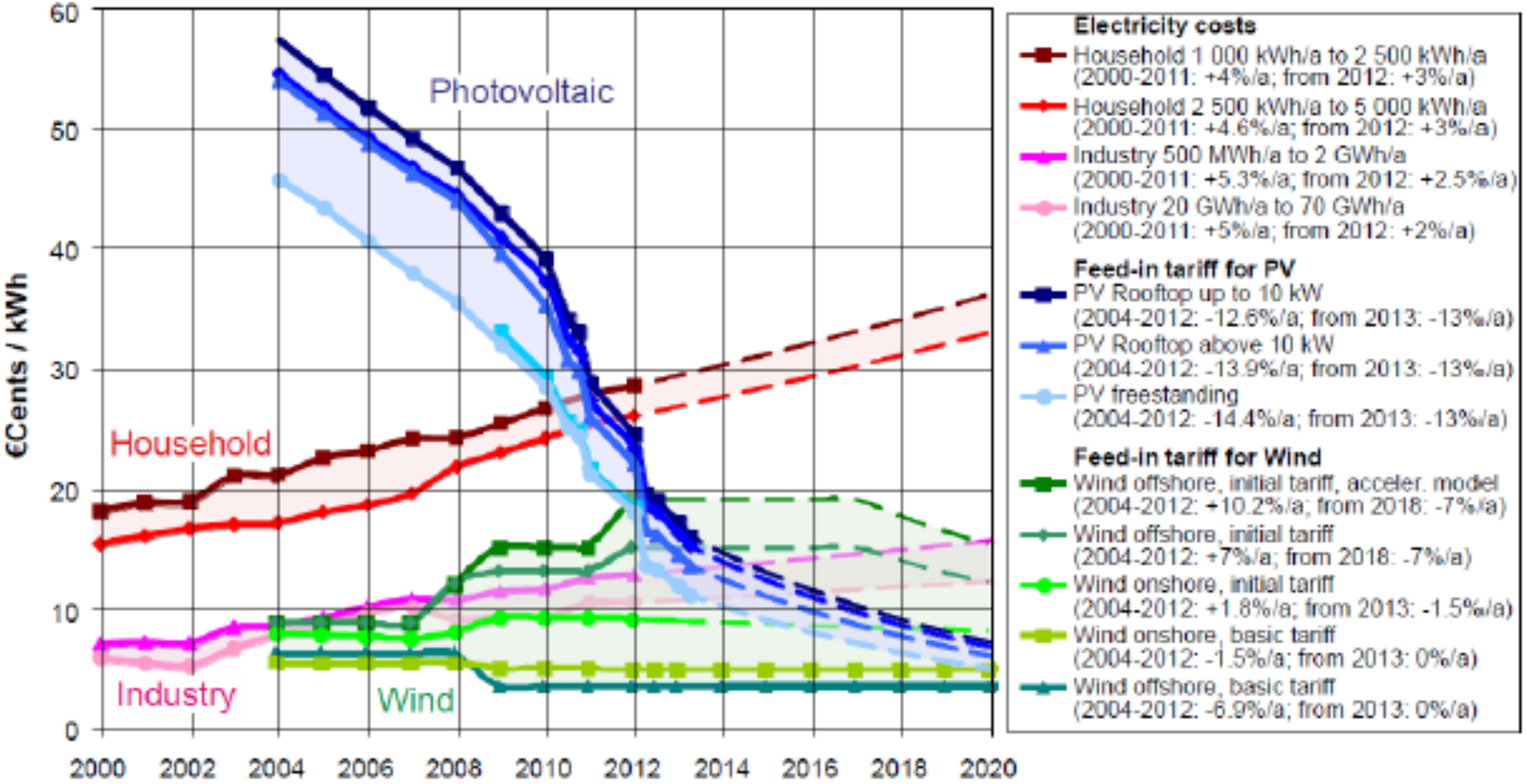
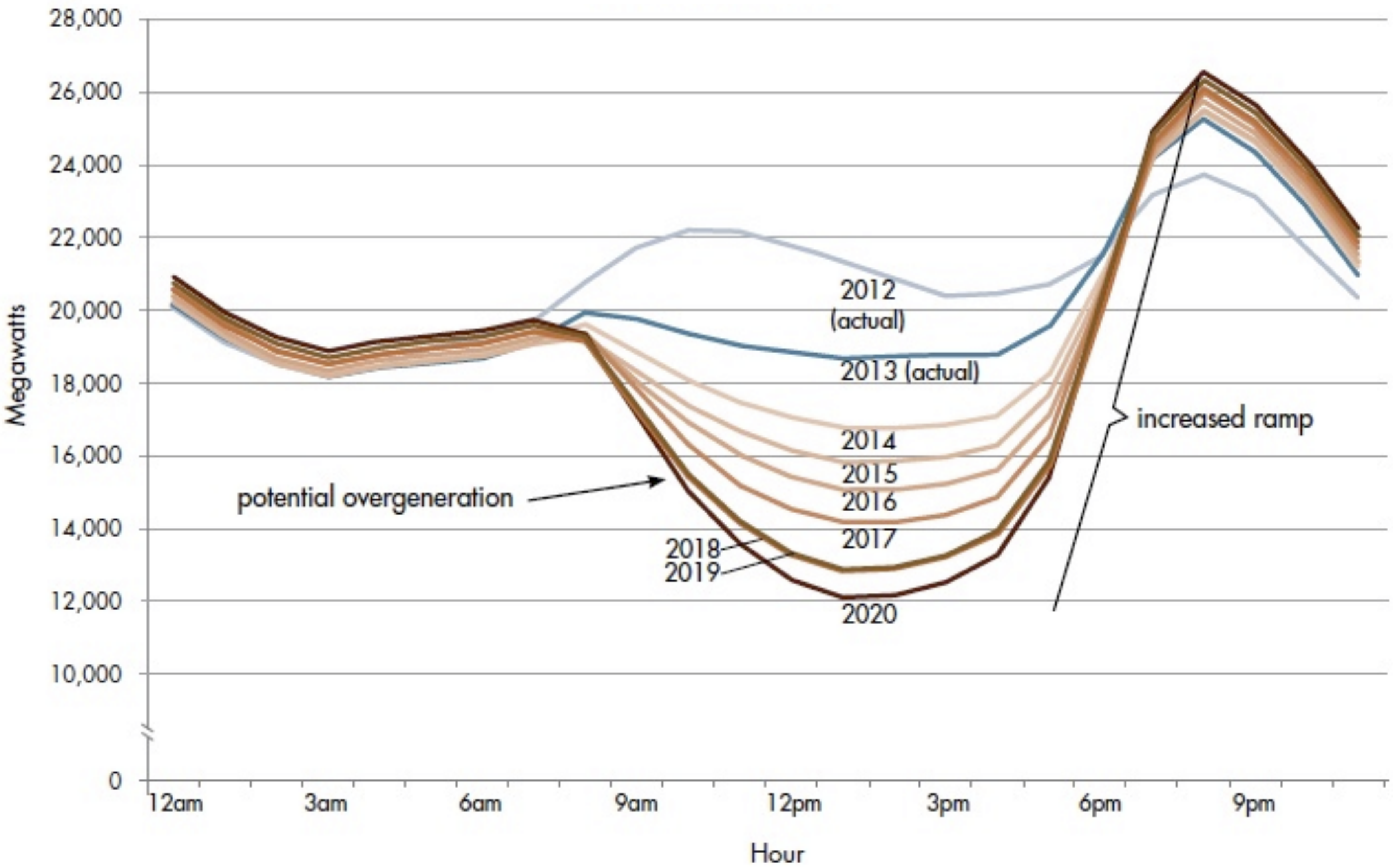
"Really ?"



The main challenge : PV and wind turbines are fluctuating !

Californian net load =total load - PV production



Hes·so// VALAIS WALLIS

The main challenge : PV and wind turbines are fluctuating !

- Restore balance *production=consumption* with storage ?
- What effect have these fluctuations on the grid ?

- The true price of renewable electricity must include additional infrastructures : storage facilities, transmission and distribution grid upgrades etc.

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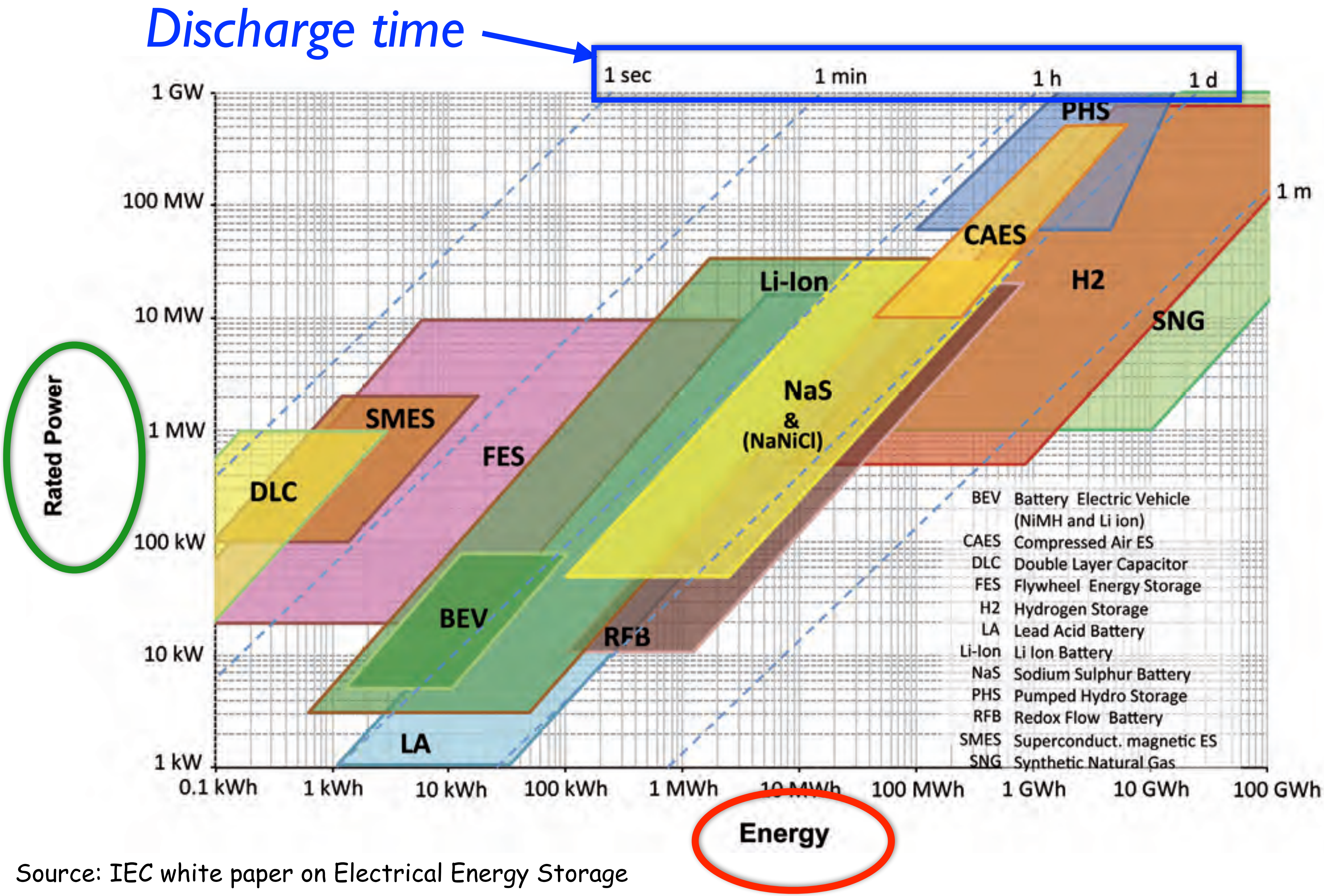
- The Energy Transition
- Storage ? What storage ?
- Demand-Side Management
- Tomorrow's Electric Production vs. the Power Grid

Storage ? What storage ?



Source: IEC white paper on Electrical Energy Storage

Storage ? What storage ?

parameter	unit	description
storable energy	kWh	maximum volume of energy that can be stored
capacity	kW	maximum discharge capability
lifetime	years / # of cycles	
efficiency	%	%-age of stored energy that can be discharged (output/input)
price	€	can be €/kW, €/kWh, **€/kWh/cycle**

Hes·so// VALAIS WALLIS

Battery storage

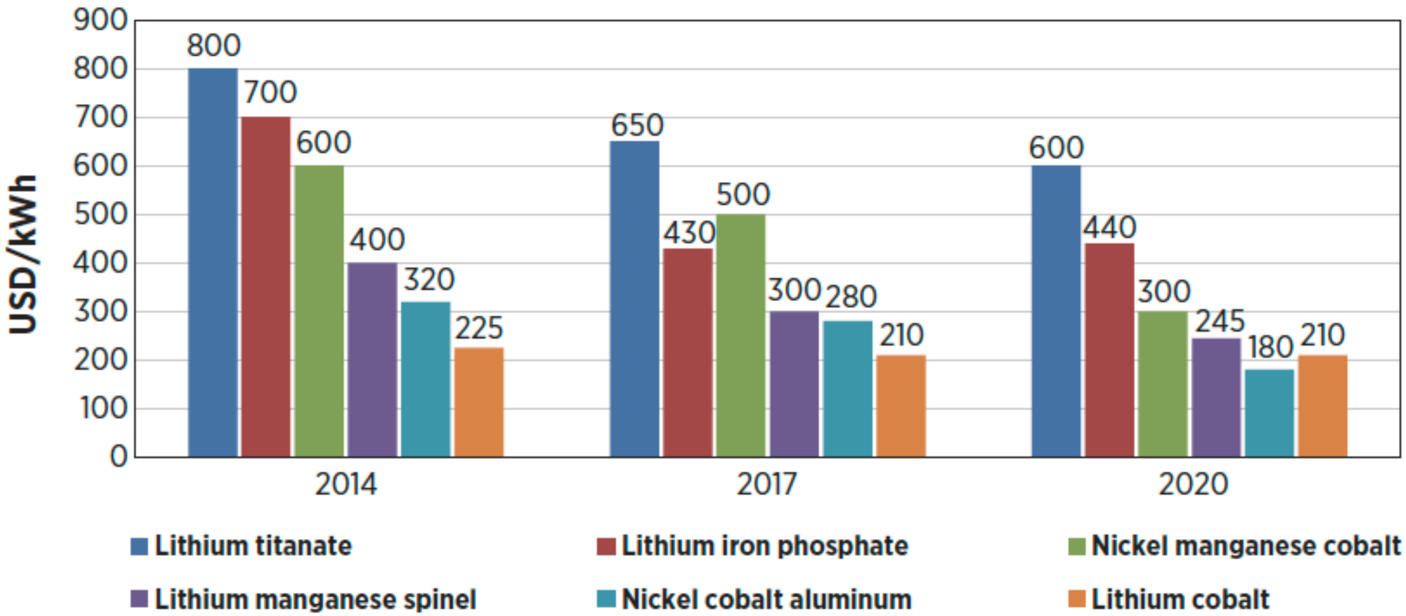
Cost of battery storage systems on German market (2015)

battery technology	lead-acid	li-ion	li-ion
battery power	5	5	5
battery capacity (kWh)	14.4	5.5	8
usable capacity (kWh)	7.2	4.4	8
cycles	2800	3000	6000
price (EUR)	8900	7500	18900
EUR/kW	1780	1500	3780
EUR/kWh	618	1364	2363
EUR/useable kWh	1236	1705	2363
EUR/useable kWh/cycle	0.44	0.57	0.39

Each kWh that is discharged costs
44, 57, 39 eurocent on top of its production cost

IRENA “Battery storage for renewables: Market Status and Technology Outlook” (2015)

Battery storage



	Cathode	Anode	Electrolyte	Energy density	Cycle life	2014 price per kWh	Prominent manufacturers
Lithium iron phosphate	LFP	Graphite	Lithium carbonate	85-105 Wh/kg	200-2000	USD550-USD850	A123 Systems, BYD, Amperex, Lishen
Lithium manganese spinel	LMO	Graphite	Lithium carbonate	140-180 Wh/kg	800-2000	USD450-USD700	LG Chem, AESC, Samsung SDI
Lithium titanate	LMO	LTO	Lithium carbonate	80-95 Wh/kg	2000-25000	USD900-USD2,200	ATL, Toshiba, Leclanché, Microvast
Lithium cobalt oxide	LCO	Graphite	Lithium polymer	140-200 Wh/kg	300-800	USD250-USD500	Samsung SDI, BYD, LG Chem, Panasonic, ATL, Lishen
Lithium nickel cobalt aluminum	NCA	Graphite	Lithium carbonate	120-160 Wh/kg	800-5000	USD240-USD380	Panasonic, Samsung SDI
Lithium nickel manganese cobalt	NMC	Graphite, silicon	Lithium carbonate	120-140 Wh/kg	800-2000	USD550-USD750	Johnson Controls, Saft

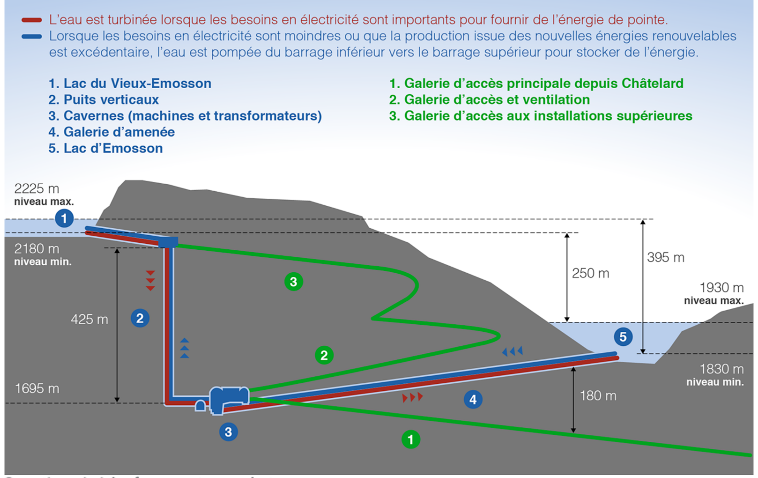
IRENA “Battery storage for renewables: Market Status and Technology Outlook” (2015) based on Jaffe and Adamson, 2014.

Pumped-hydro storage

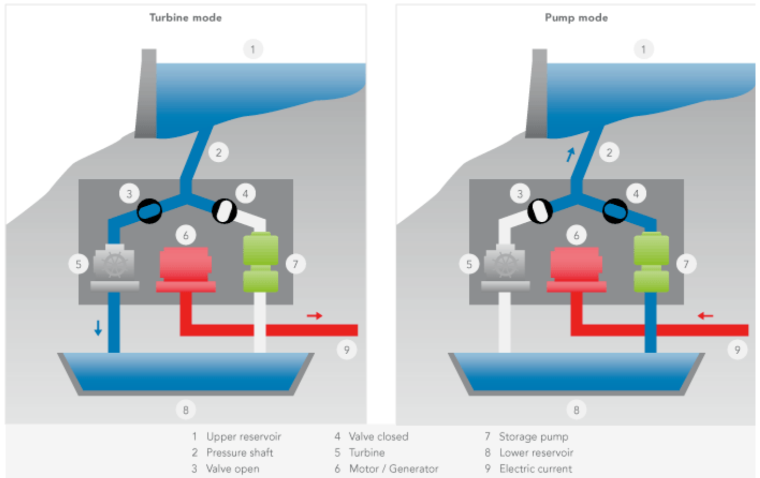
Two projects under achievement in CH

- Nant-de-Drance (2019)
  storable energy 20GWh
  cost : 2Mia €
- Linthal (2015)
  storable energy 40GWh
  cost : 2Mia €

-> 50-100€/kWh
-> full cycle in 1-2 days
-> ~50 years lifetime
-> yet, financial trouble…



Operating principle of a pump-storage plant



Storage ? What storage ?

It seems fair to say that, in the foreseeable future, storage costs will be at least equal to, or larger than production costs.

-> Viable scenarios for the energy transition should use as little storage as possible

-> Try and use what is already available :

-seasonal fluctuations : (1) standard dam-hydro

-daily fluctuations : (2) pumped-hydro
(3) demand-side management

Storage ? What storage ?

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(3) demand-side management

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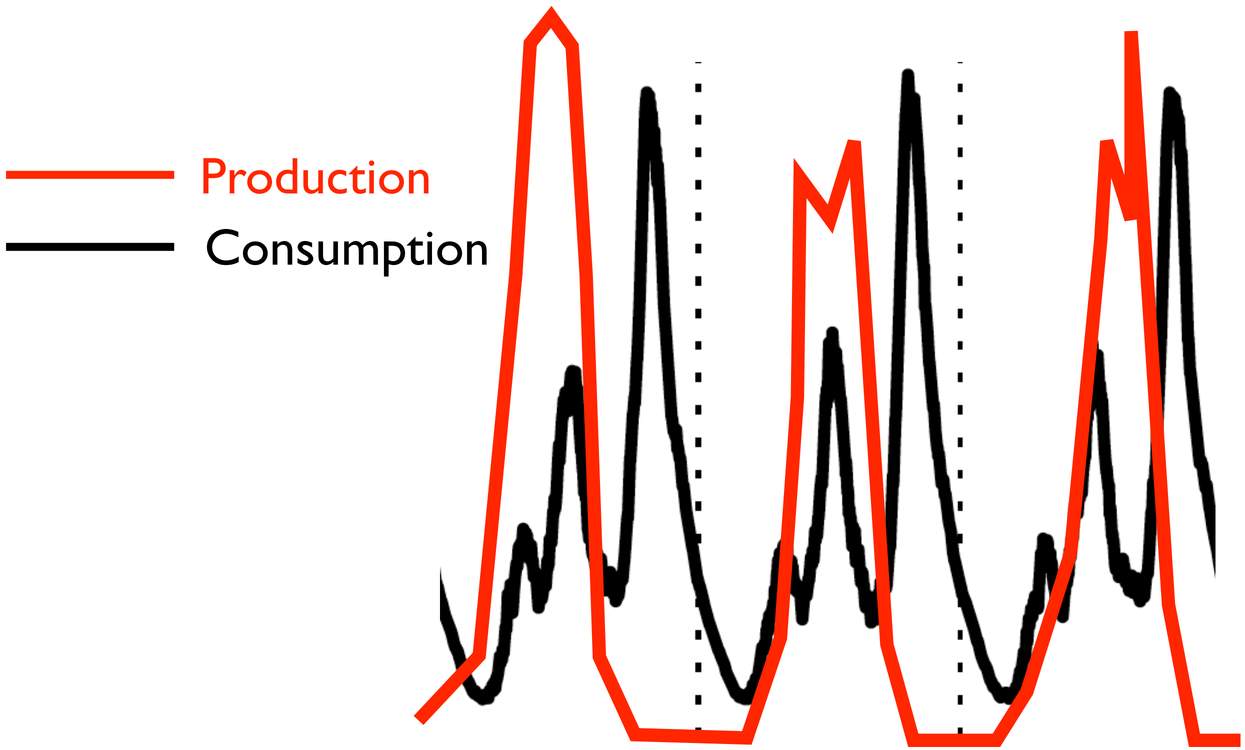
Demand-side management

Operating conditions:

Balance production=consumption at all times!

Old model : adapt production to consumption
Demand-side management : adapt consumption



Demand-side management

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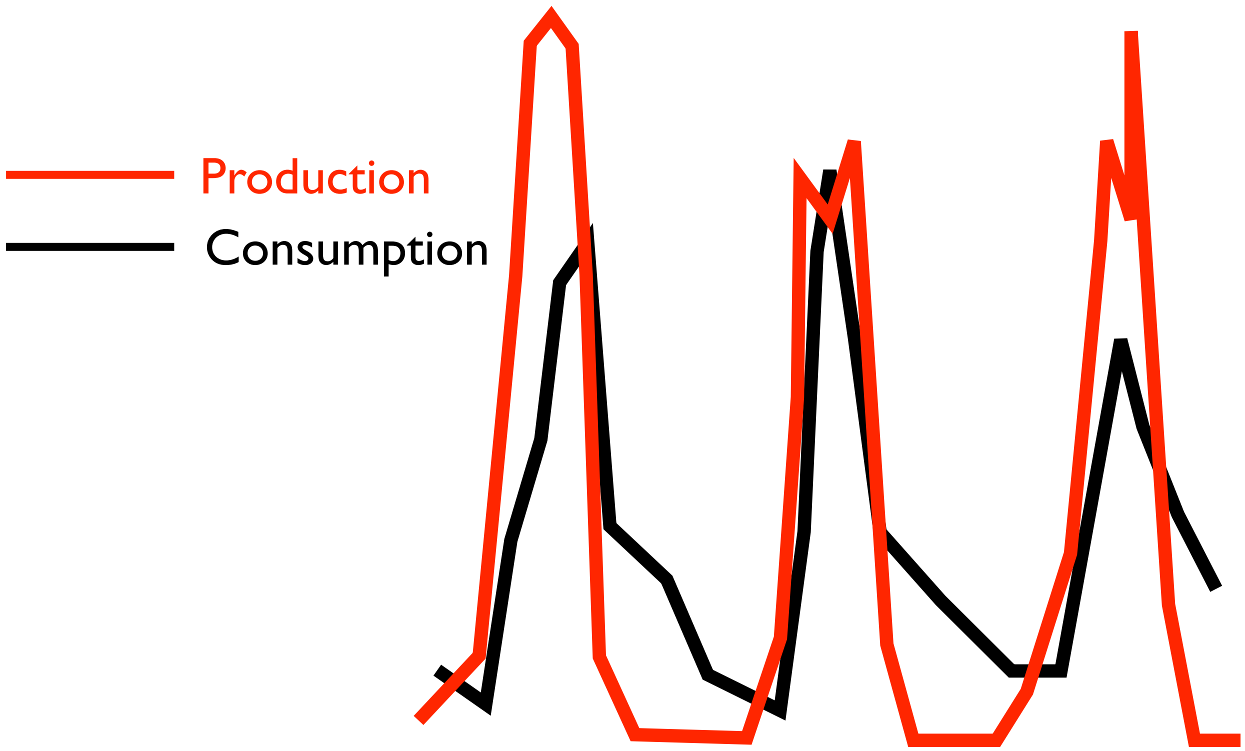


Demand-side management

Need to identify loads that are

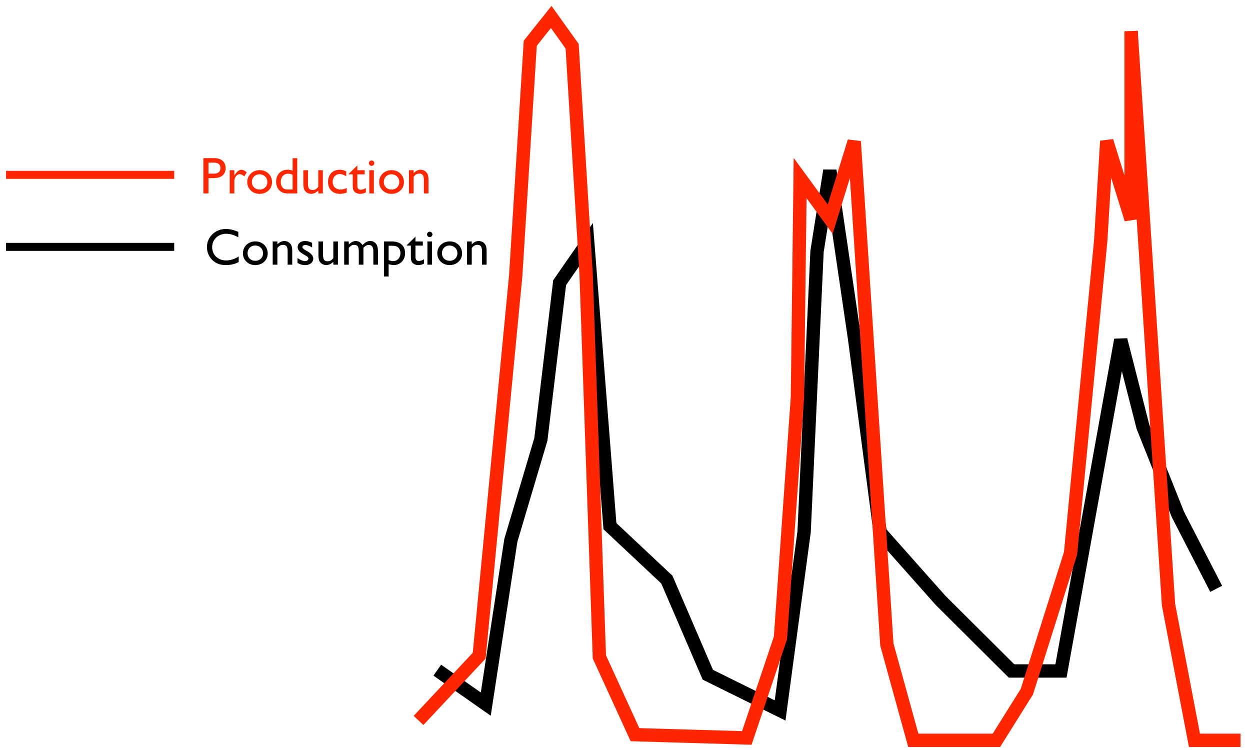
-large enough (worth it)
-flexible enough

Thermostatically controllable loads

- *electric household heating*
- *domestic hot water heating*

Not this talk

- washing machines, dryers etc.
- electric cars



Demand-side management with thermal loads

- heating of house (heat pumps; electric heaters)
- heating of domestic hot water (electric boiler)

main variable T_i : -inside temperature of house/boiler #i

- time-dependent
- $T_i \in [T_{min}, T_{max}]$

$T_{min} = T_{ref} - \Delta$ $T_{max} = T_{ref} + \Delta$

- Time-evolution determined by

thermal conductivity

external temperature

heating/cooling heat pump, AC, …

$$C\frac{dT_{\mathrm{i}}}{dt} = K[T_{\mathrm{e}}(t) - T_{\mathrm{i}}(t)] + GI(t) + P(t)$$

inertia =storage/destorage

solar gains

Demand-side management with thermal loads

- Time-evolution determined by

thermal conductivity

external temperature

heating/cooling heat pump, AC, …

$$C\frac{dT_{\rm i}}{dt} = K[T_{\rm e}(t) - T_{\rm i}(t)] + GI(t) + P(t)$$

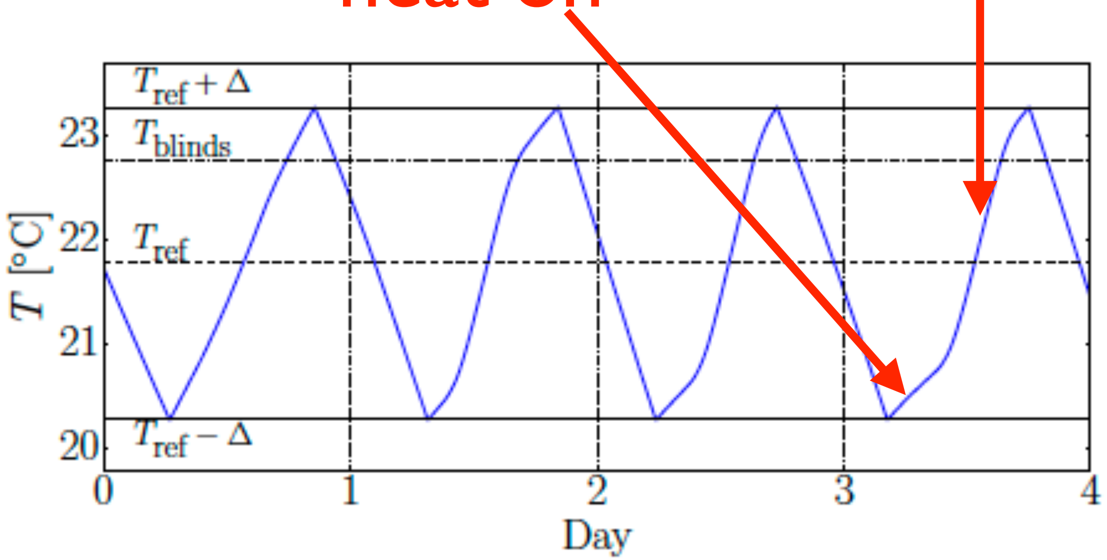
inertia =storage/destorage

solar gains

- Solar gains + external temperature : weather forecast
- $T_i \in [T_{min}, T_{max}]$

Uncontrolled :

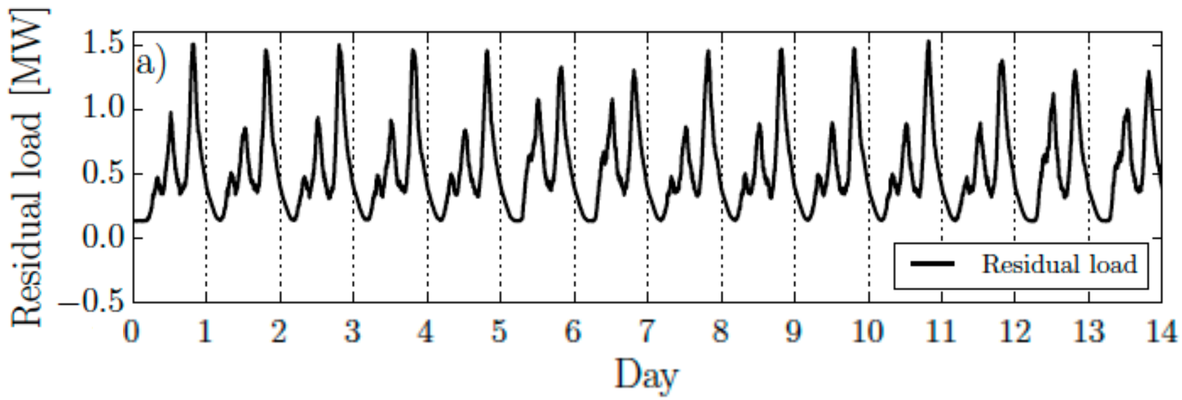
$T_i = T_{min}$, $P(t)=1$
T_i goes up
$T_i = T_{max}$, $P(t)=0$
T_i goes down, $P(t)=0$



Modeling household loads : BEHAVSIM

P Ferrez and P Roduit, “Non-intrusive appliance load curve disaggregation for service development,” in IEEE International Energy Conference (2014)

BEHAVSIM : software that simulates household loads from domestic appliances (no heating) as well as domestic water flow

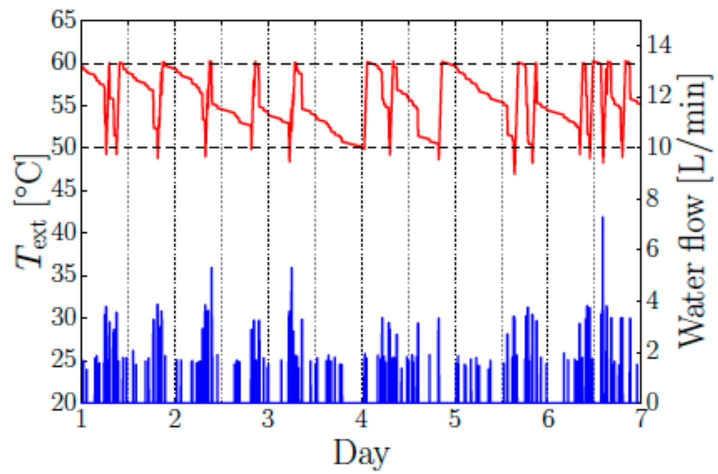


Idea : group of households (1000)

PV production (up to 5kW$_p$/house)

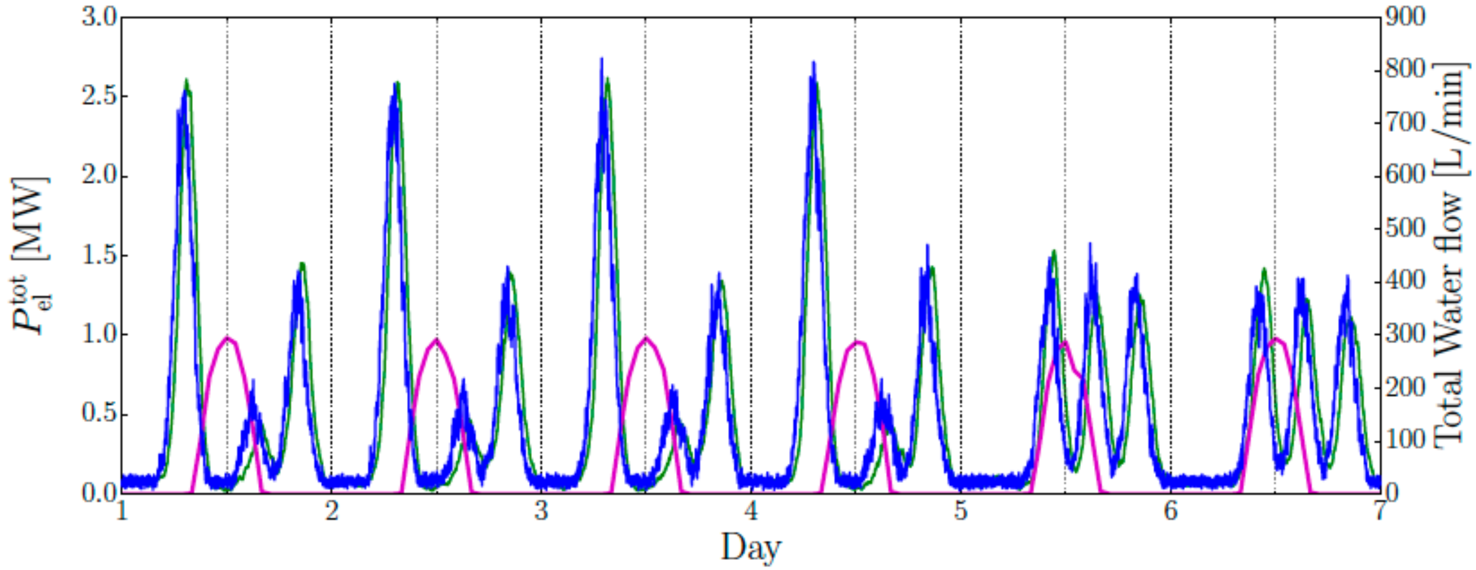
meteo data

simulate electric load with various controls over heat pumps and water boilers



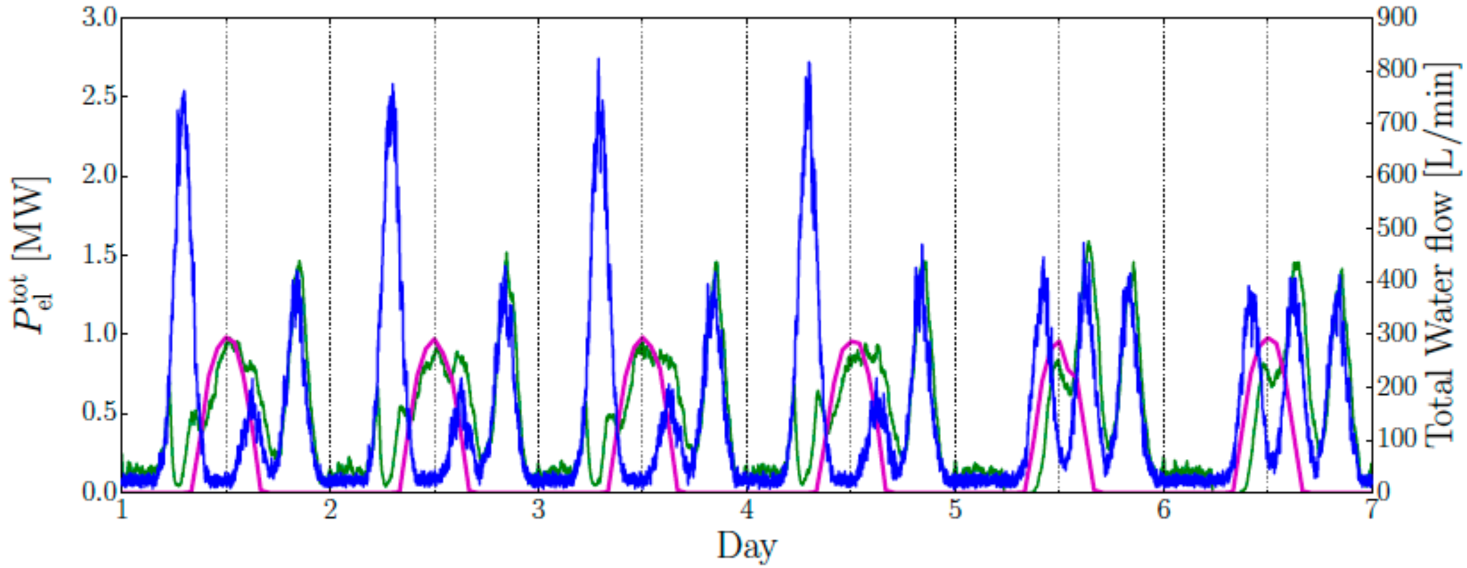
Shifting thermostatically controlled loads : domestic hot water

No control



Water consumption — Load from water heating — PV production

Control

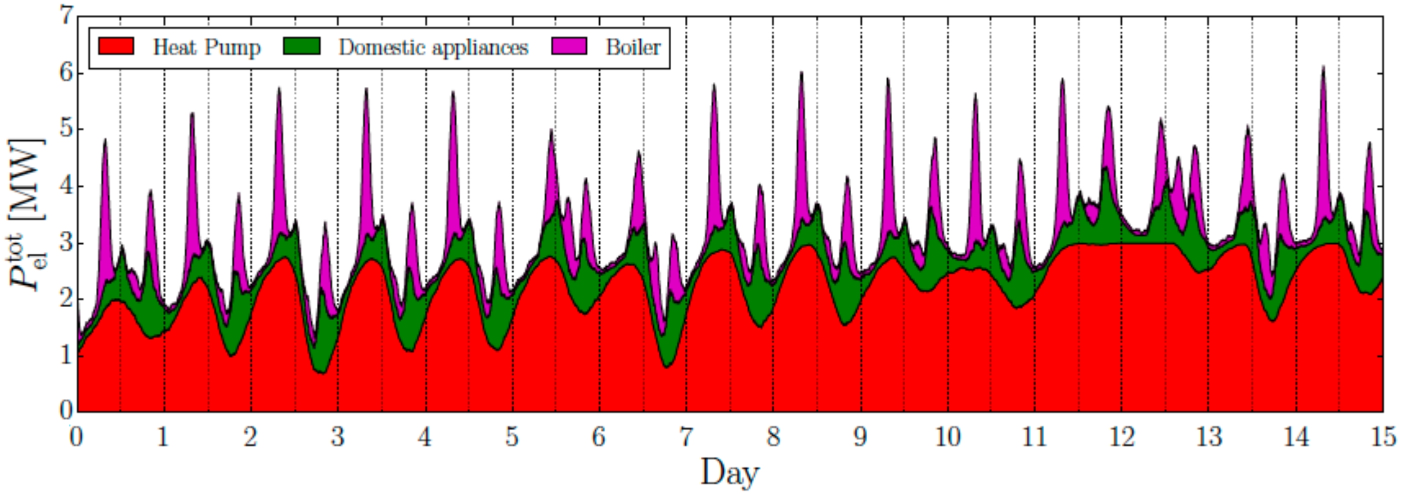


1000 houses with ~1.5kW$_p$ of pv each

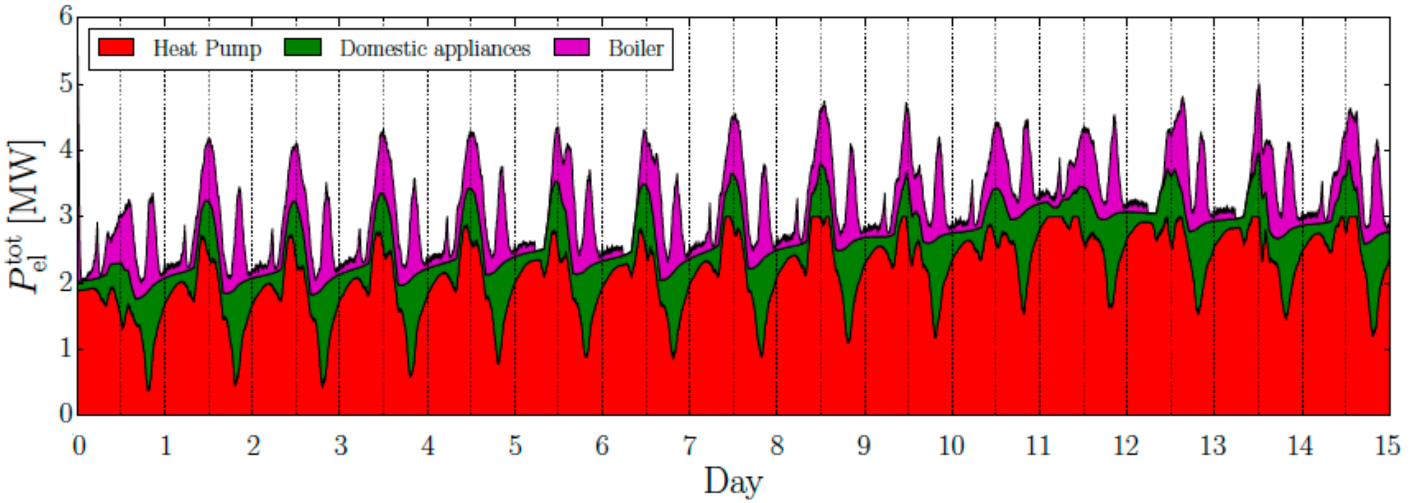
DSM with domestic hot water + heating

Total consumption for 1000 households in January in Sion, CH

No control



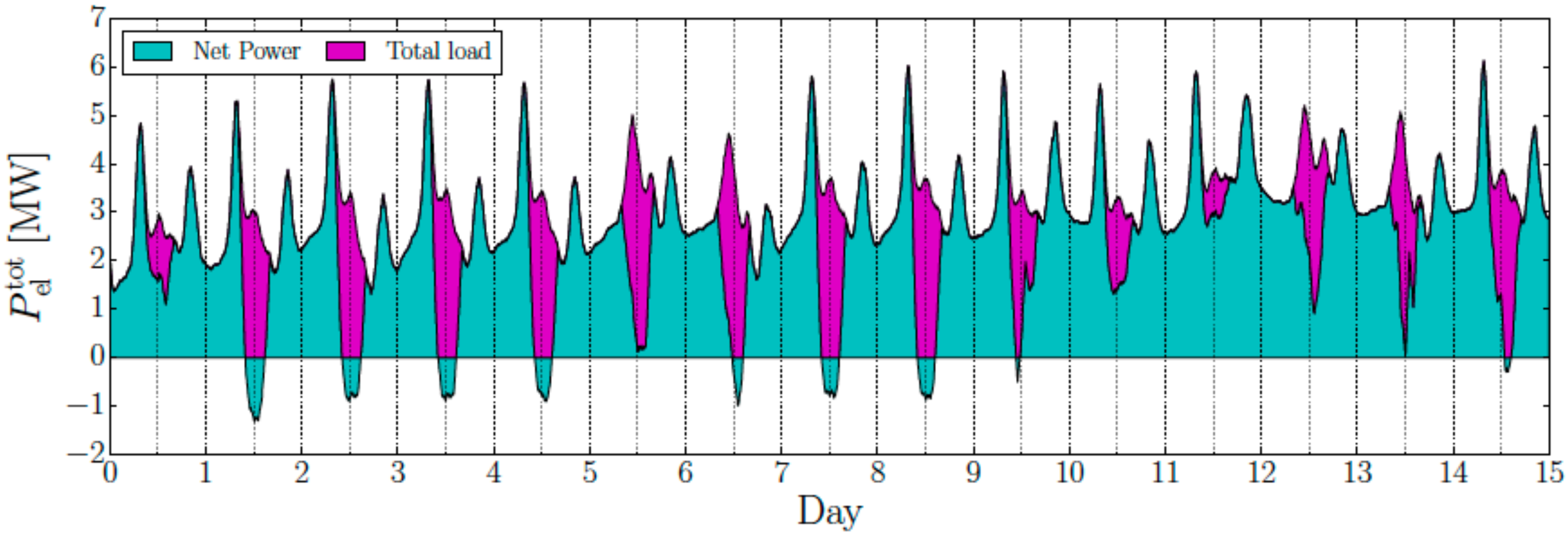
Control



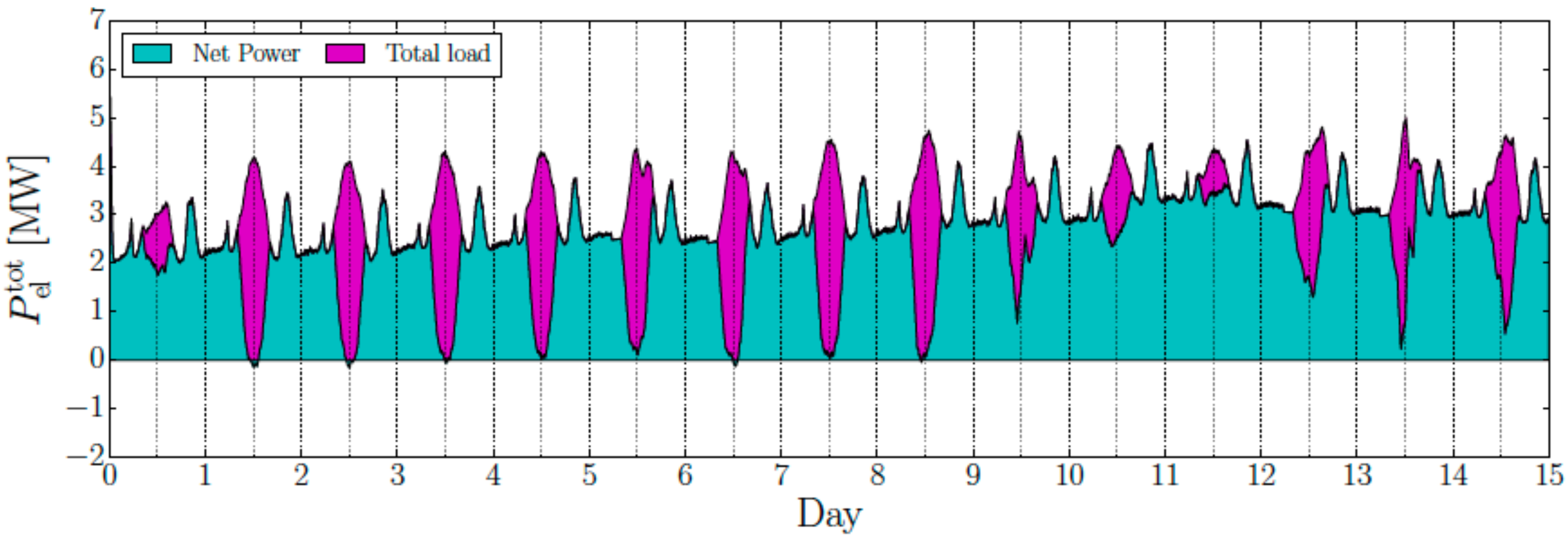
DSM with domestic hot water + heating

Total load for district of 1000 households in January in Sion, CH

No control

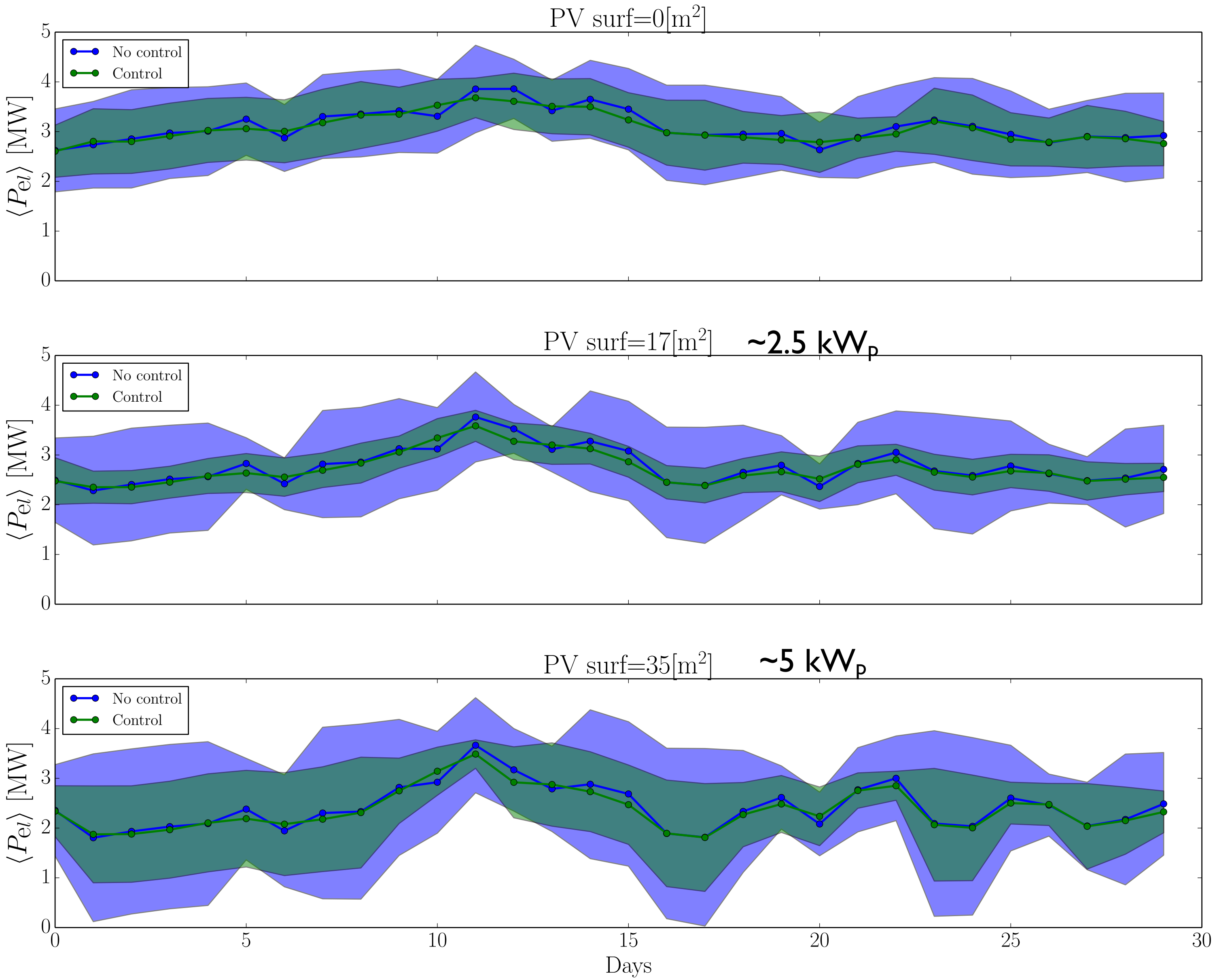


Control



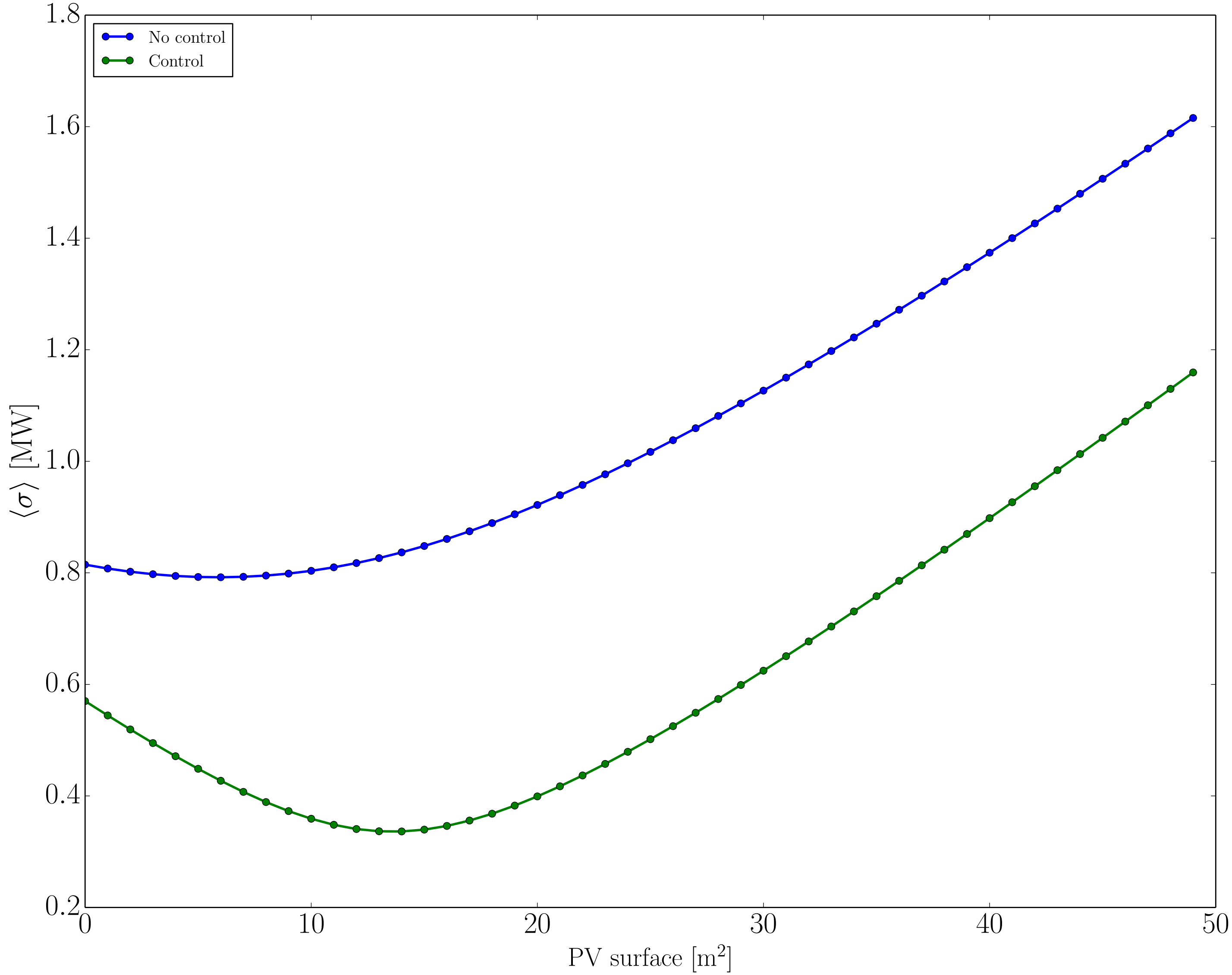
DSM with domestic hot water + heating

Total load on district trafo for 1000 households in January in Sion, CH



DSM with domestic hot water + heating

Total load on district trafo for 1000 households in January in Sion, CH



Demand-side management : to-do list

(1) Put houses on transmission grid :
-do we need to reinforce the grid ? (€?)

(2) Add other loads (washing machines+dryers+el. cars)
-get estimate for total gain from DSM

(3) Evaluate how much renewable productions will be transferred to the high voltage grid; see how much more large-scale (pumped-hydro) storage we need.

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Energy transition and the high voltage grid

Goal : to find

(i) how much will we need to upgrade the transmission grid to incorporate tomorrow's penetration of RE
(ii) what productions will be valued by the energy transition, which one will be losers (future of hydro ?)
(iii) how much large-scale storage we will need (GW, GWh)

Steps :

(i) construct and calibrate model
(ii) get results for 2020, 2025, 2030 …

Energy transition and the high voltage grid
(1) current and future european productions

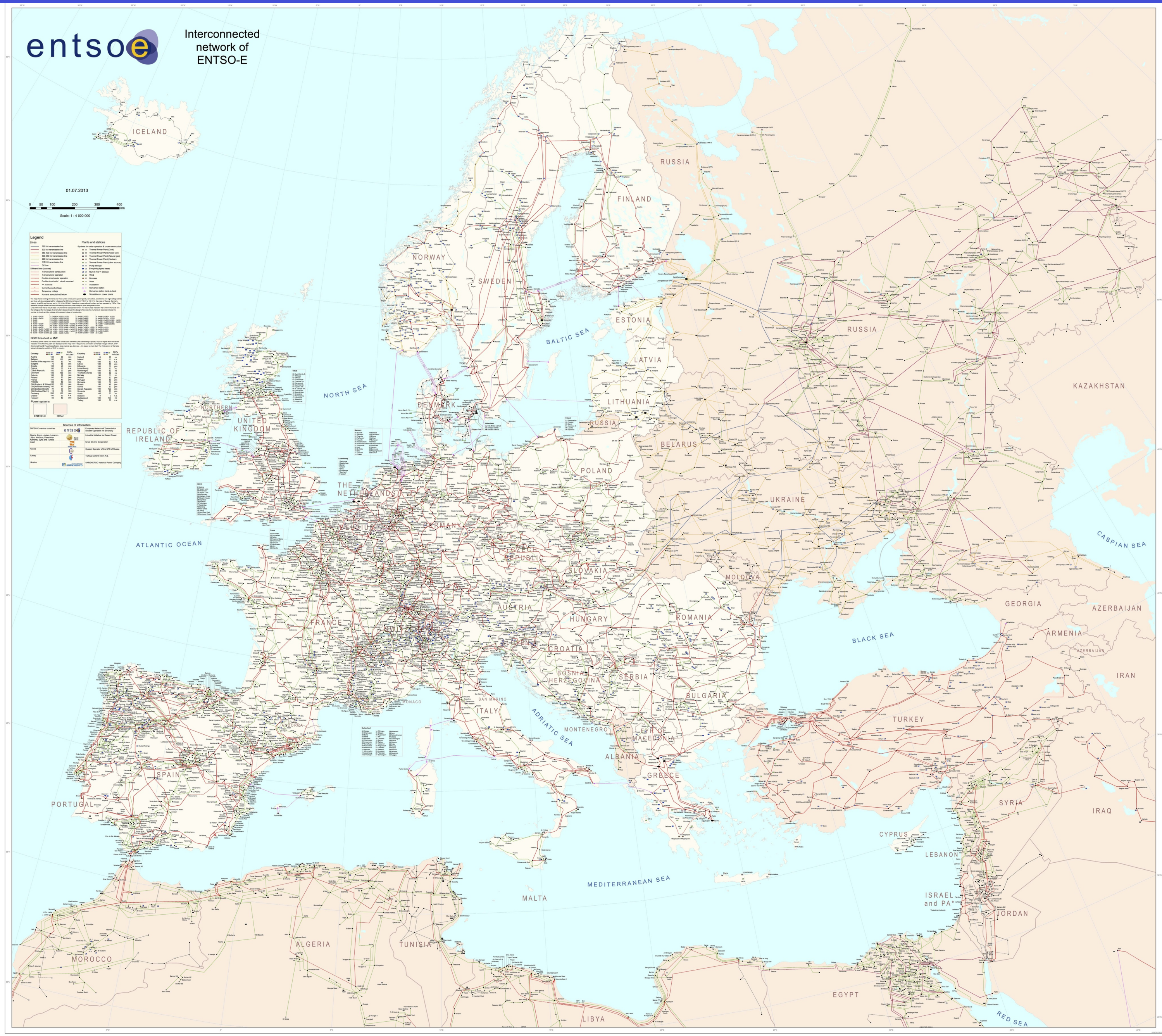
entsoe

TYNDP 2016
Scenario Development Report

TABLE 11 2030 VISION 4 - INSTALLED CAPACITIES (MW)

Country	Biofuels	Gas	Hard coal	Hydro	Lignite	Nuclear	Oil	Others non-RES	Others RES	Solar	Wind
AT	0	6030	0	22244	0	0	196	990	1200	3000	4750
BA	0	373	0	2618	992	0	0	0	0	100	770
BE	0	9740	0	2226	0	0	0	3200	2500	4925	6953
BG	0	1500	710	3468	487	2000	0	0	0	2974	1450
CH	0	0	0	19745	0	1145	0	990	1120	5658	295
CZ	0	3135	310	2170	5330	1880	0	0	1110	3690	880
DE	0	37392	14940	11072	10209	0	871	10630	9340	58990	95174
DK	1460	3793	410	9	0	0	735	0	260	1405	10719
EE	656	94	0	20	0	0	0	1010	300	50	525
ES	0	27539	0	25635	0	7120	0	12210	5100	42818	43409
FI	580	970	0	3400	0	3350	2165	1390	4670	1300	3750
FR	0	14051	1740	27200	0	37646	819	5400	4800	18200	52910
GB	0	36616	0	5470	0	9022	75	4110	8420	11915	58174

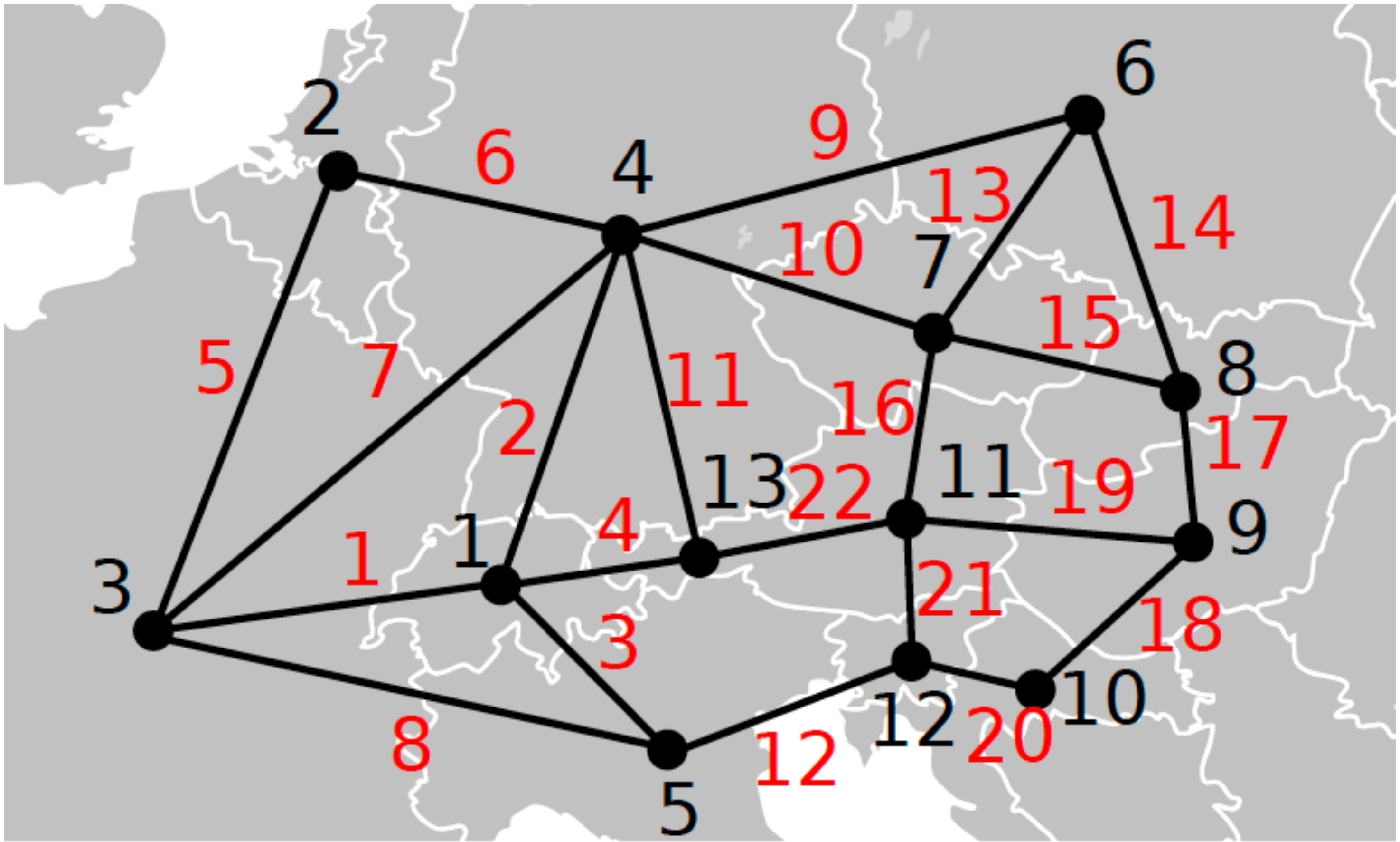
Energy transition and the high voltage grid
(2) modeling the grid



Energy transition and the high voltage grid
(2) modeling the grid

Difficulty to predict precise location of each planned production in each european country

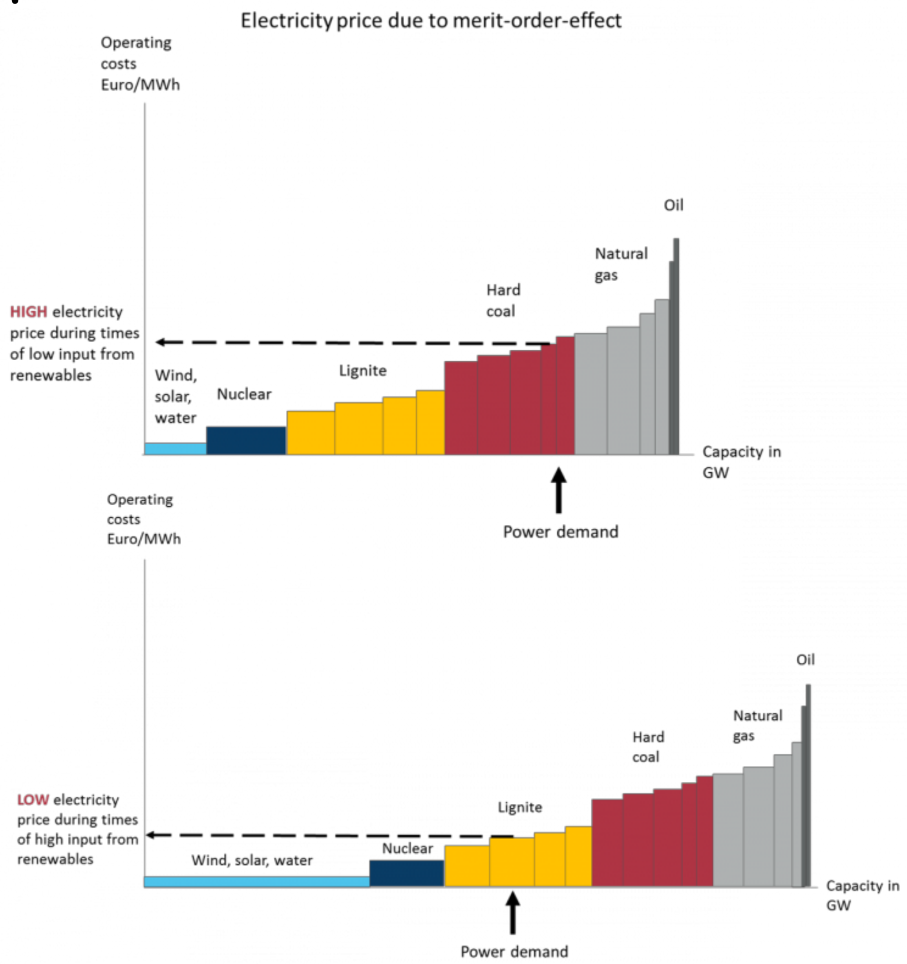
-> Use aggregated, *equivalent* model



Energy transition and the high voltage grid (3) dispatching productions

Power plants are dispatched based on

(i) their operating cost
-> merit order :



(ii) their ramp rate P_{max}/hour
~how fast can they start to produce

Energy transition and the high voltage grid
(3) dispatching productions

Strategy :

(1) separate flexible from non flexible productions and
define the residual consumption :

$$C_R = C - P_{nonflexible}$$

(2) define a cost function for each type of flexible production in each country

$$X = a\,P + b\,P^2$$

a : "operating costs" b : smoothens P before one hits P_{max}

(3) minimize total cost under constraints :

(3.1) $P < P_{max}$ for each production in each country

(3.2) $dP/dt < R$ i.e. maximal ramp rate for that particular technology

(3.3) total flexible production = C_R at all times

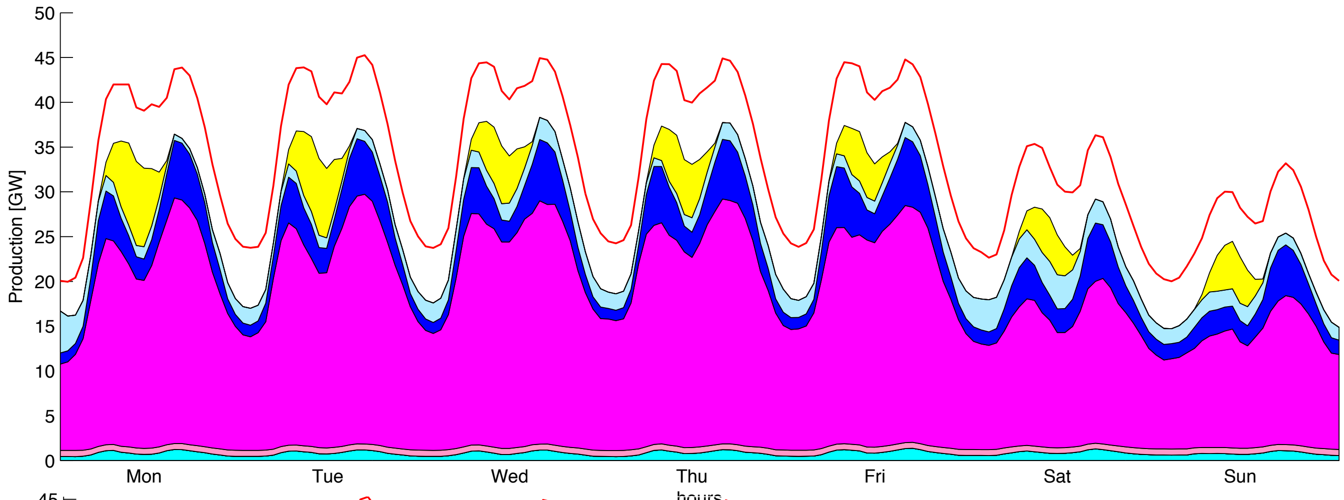
(3.4) do not exceed thermal limit of transmission lines

Energy transition and the high voltage grid
(3) dispatching productions

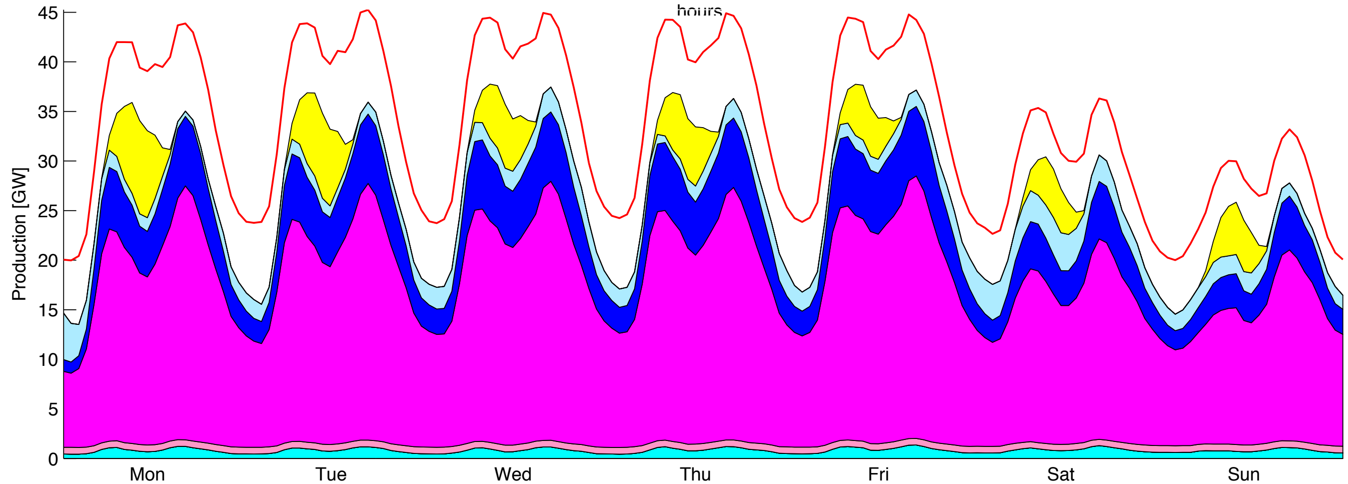
Calibration: comparing calculated with true 2015 productions
(i) Italy

gas dams run of r. wind pv

True



Calculated

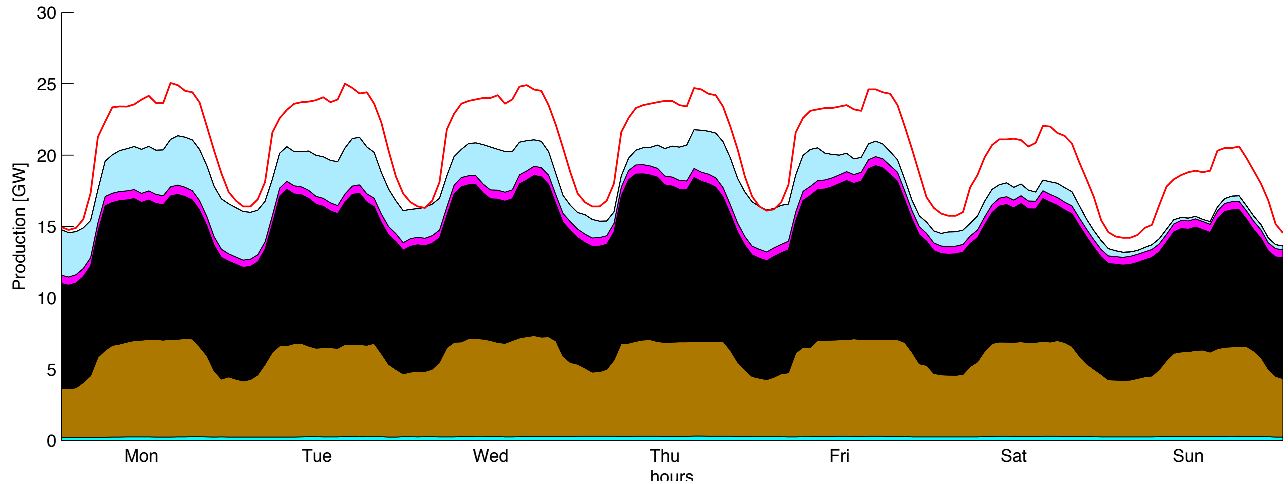


Energy transition and the high voltage grid (3) dispatching productions

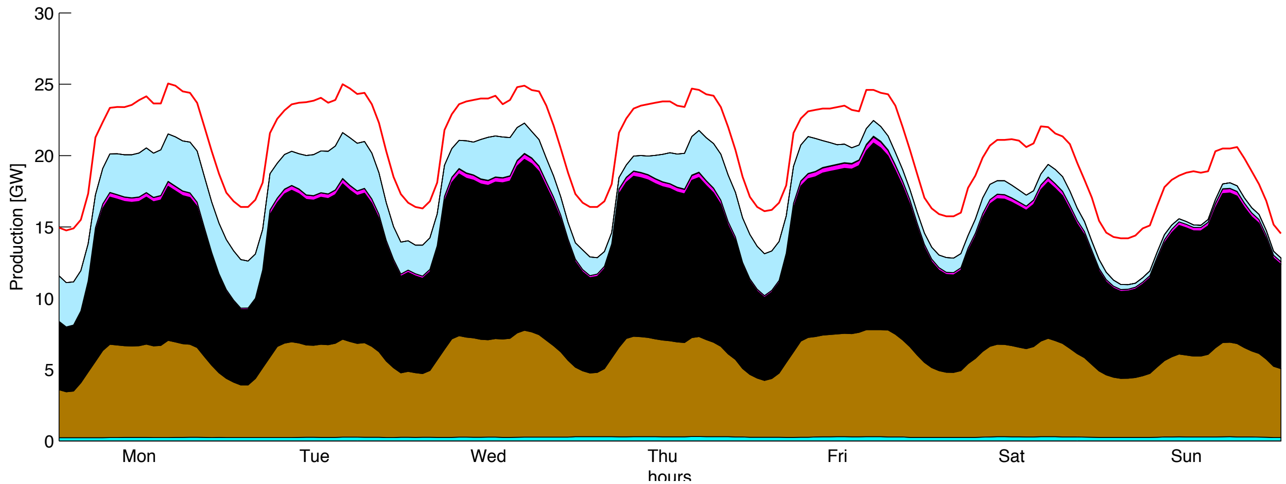
Calibration: comparing calculated with true 2015 productions (ii) Poland

lignite hard coal gas wind

True



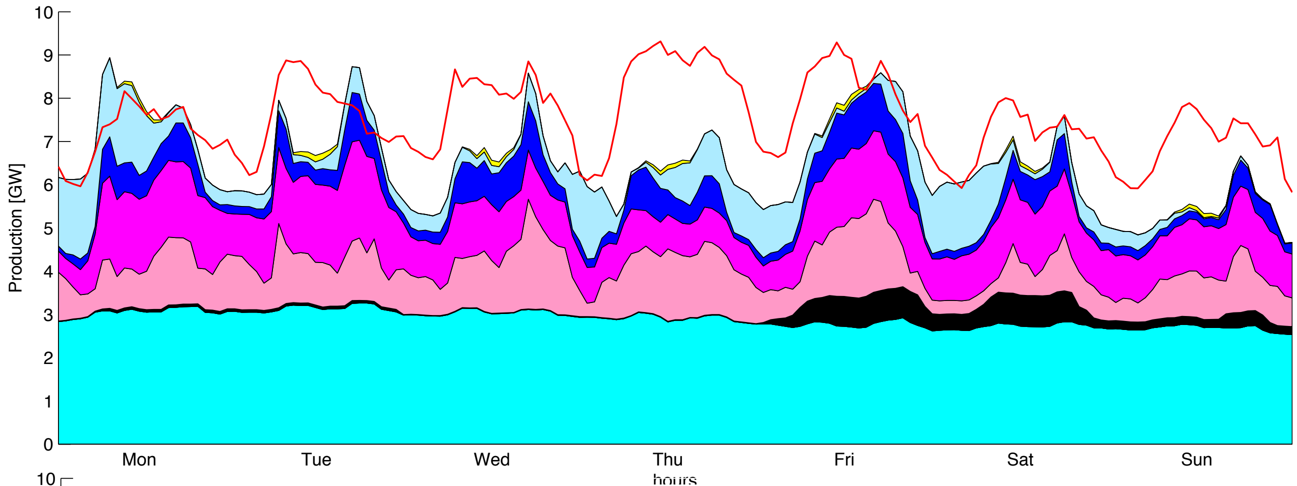
Calculated



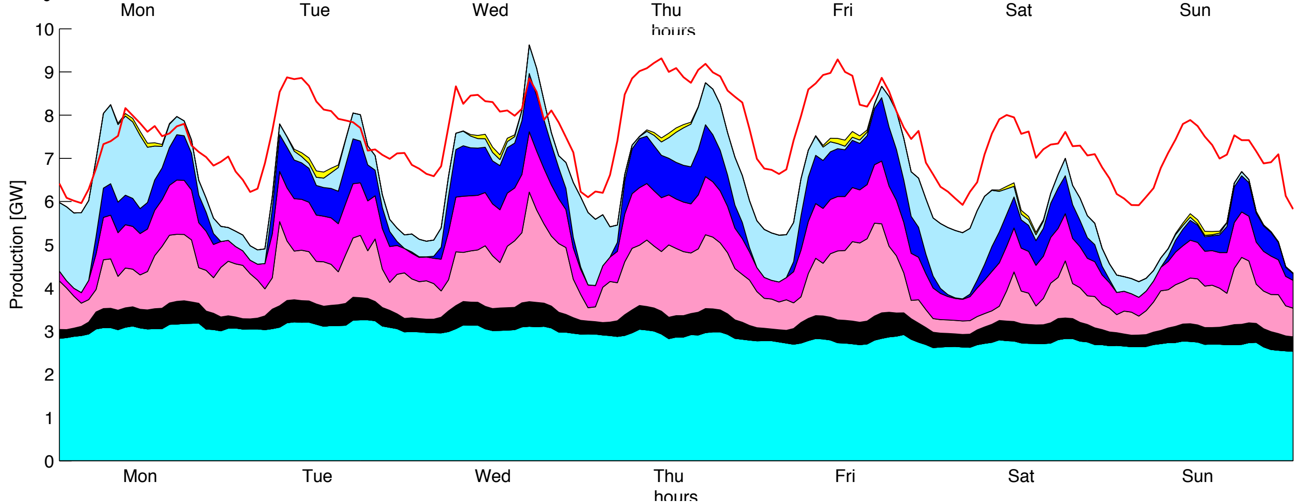
Energy transition and the high voltage grid
(3) dispatching productions

Calibration: comparing calculated with true 2015 productions
(iii) Austria

True

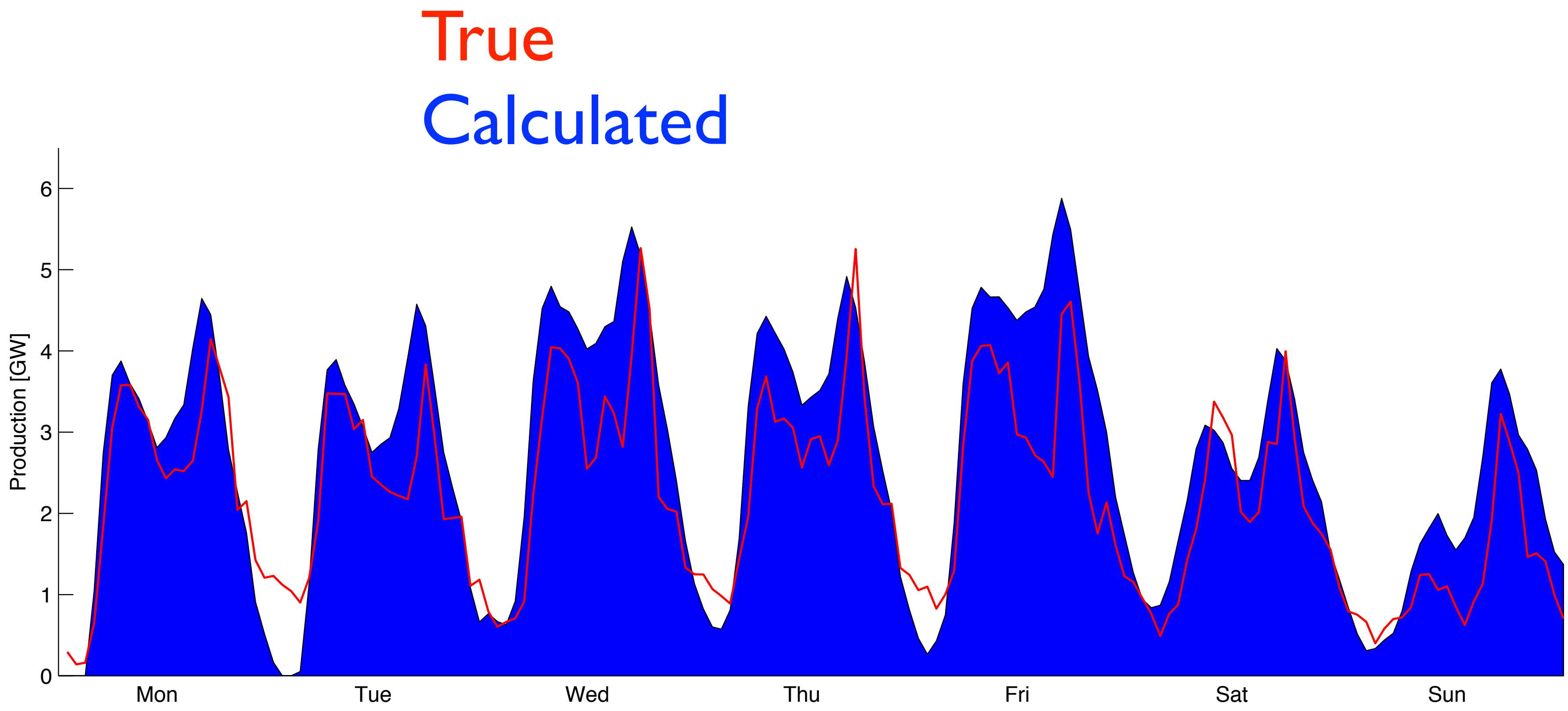


Calculated



Energy transition and the high voltage grid (3) dispatching productions

Calibration: comparing calculated with true 2015 productions (iv) CH dam-hydro

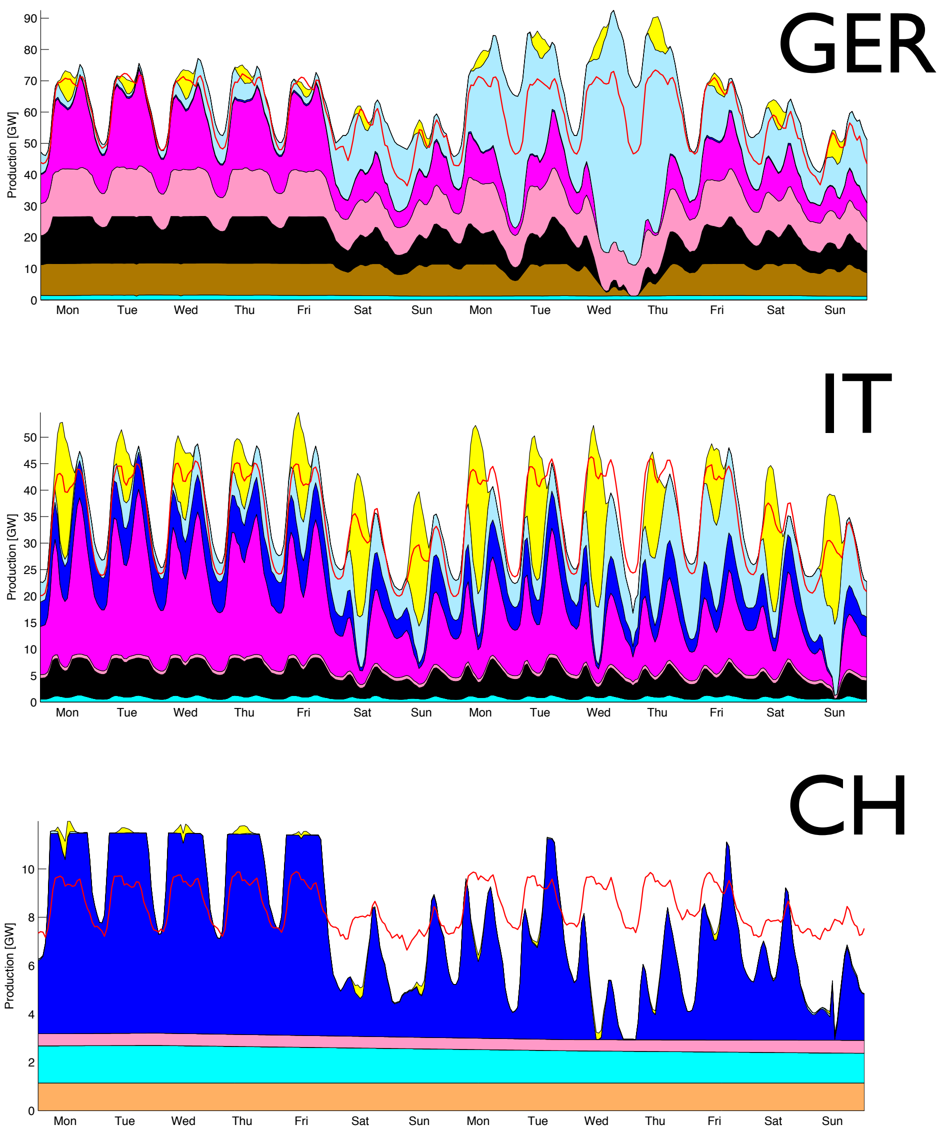


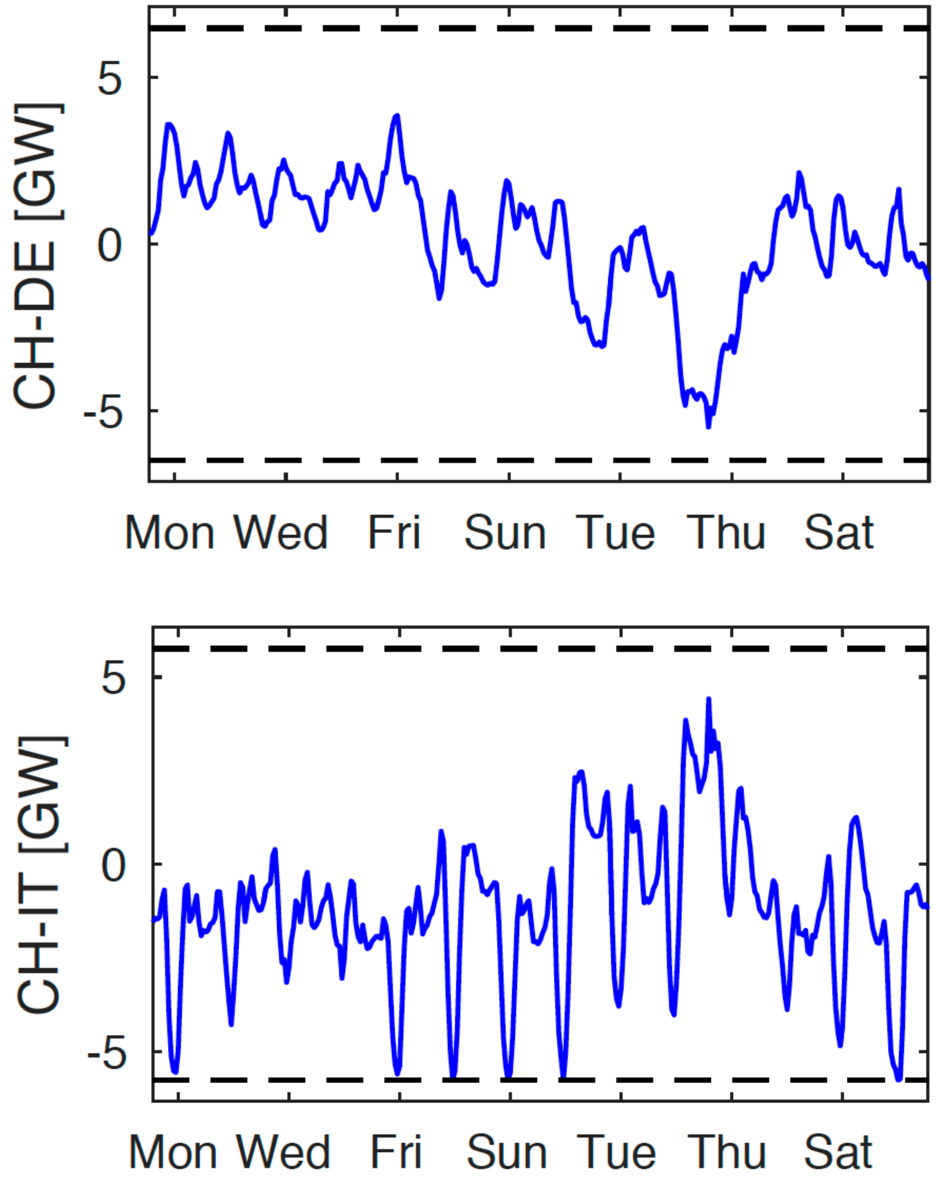
Energy transition and the high voltage grid (3) dispatching productions

Conclusion

"We can effectively model economical conditions and technological constraints with very few parameters !!!

Energy transition and the high voltage grid (4) 2030 : preliminary results





Investigating the energy transition

- Integrated top-down and bottom-up approach

- Estimate storage needs in light of dsm potential and modified dam-hydro usage

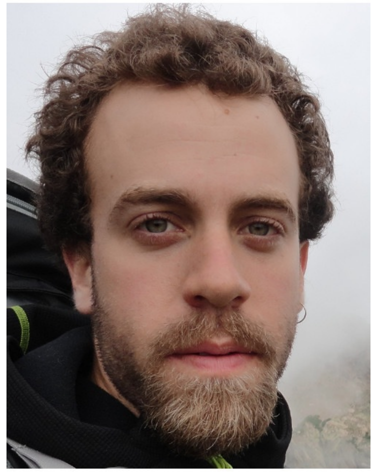
- Tools to investigate future productions and loads on grid : (i) dispatch
  (ii) aggregated model

To do : *extend aggregated model to Norway-Sweden
(at least - flows out of Germany too large)

*increase resolution step by step

The team

Tommaso Coletta, postdoc



Robin Delabays, PhD student

Laurent Pagnier, PhD student

You ? PhD student position open

ask me or philippe.jacquod@hevs.ch