POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Accounting for power sector variability in the REMIND Model

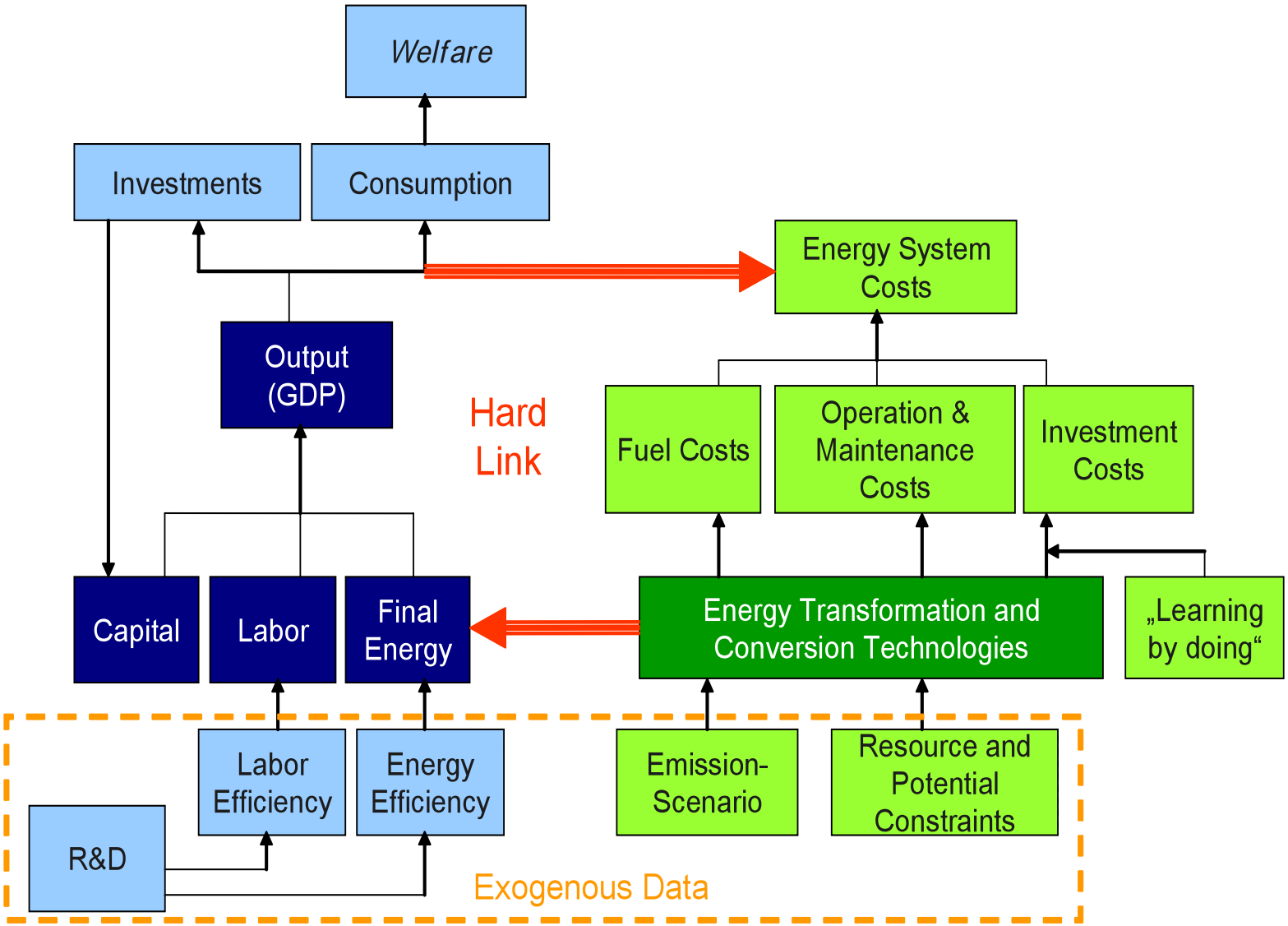
Falko Ueckerdt, Eva Schmid, Gunnar Luderer, Elmar Kriegler

Workshop on Improving the Representation of Renewables in IAMs
Snowmass, August 3, 2010

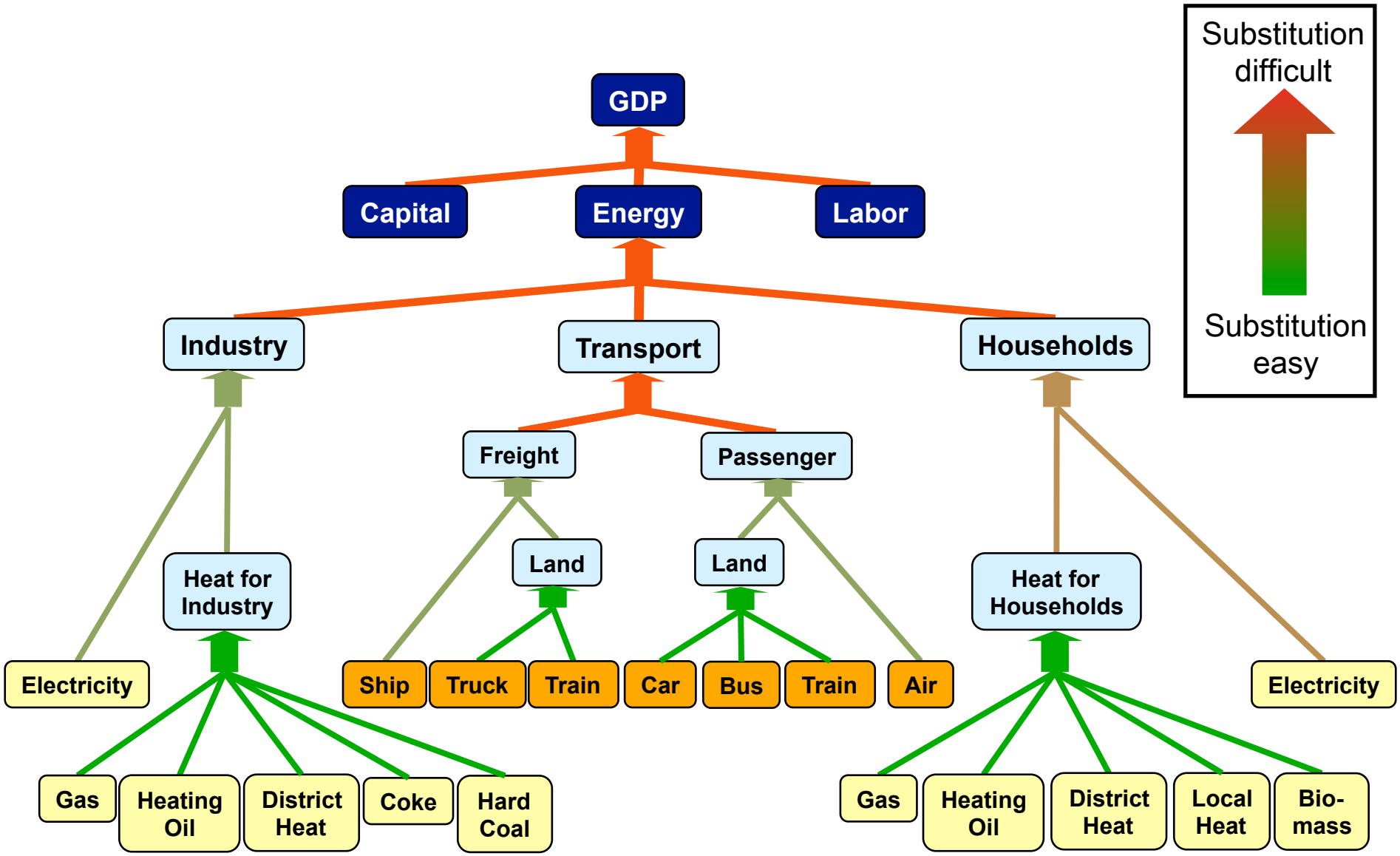
Leibniz Gemeinschaft

Potsdam Institute for Climate Impact Research
Research Domain Sustainable Solutions

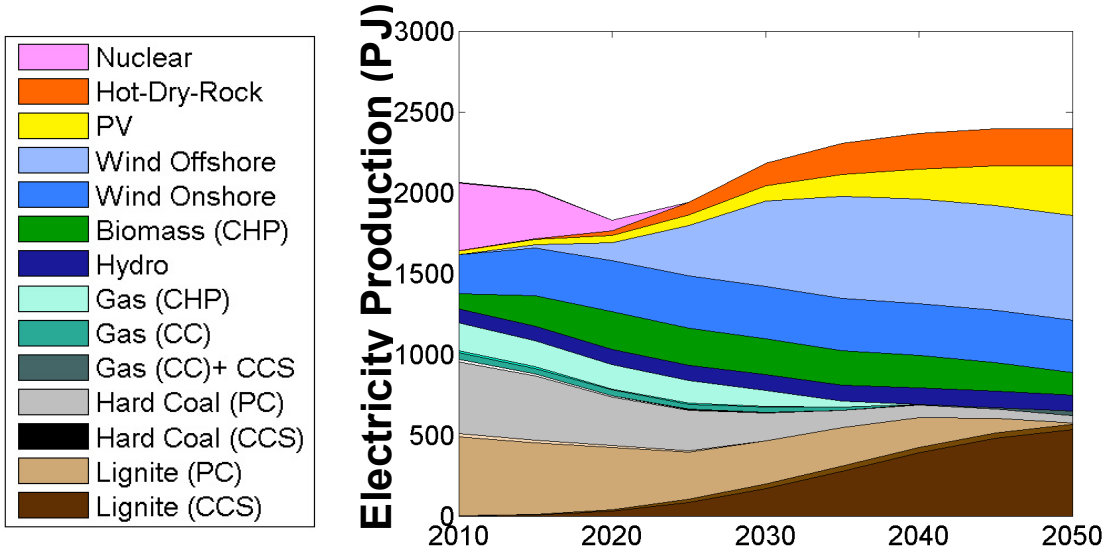
REMIND-D: A Coupled energy-system and macroeconomy model for Germany



REMIND-D: CES-Production Function



An exemplary climate policy scenario with no constraints to renewable energy integration in the power sector



- Carbon budget for Germany's energy sector:
  ~20 $GtCO_2$ (2010-2050)
  (75% reduction 2050, base year 1990)*
- Only domestic mitigation options (no emissions trading)
- Nuclear phase out
  (until 2023)**

- However
  - no constraints to renewable energy integration in the power sector applied
    → power sector variability and reliability need to be accounted for

* Target of German government: 80% reduction 2050 (base 1990)
** according to current German law

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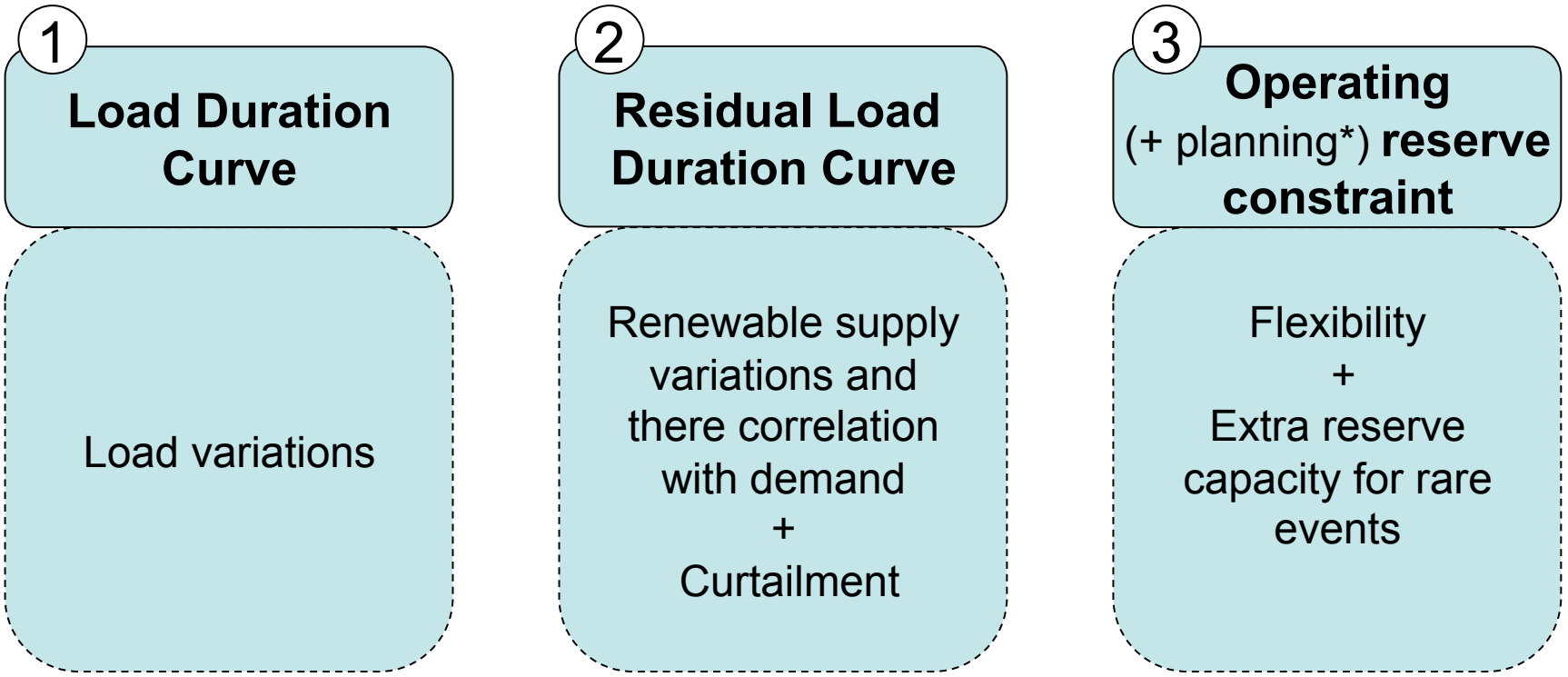
Overview of the approach



* Planning reserve constraint is well-known and does hardly change the results. Therefore it is not shown explicitly.

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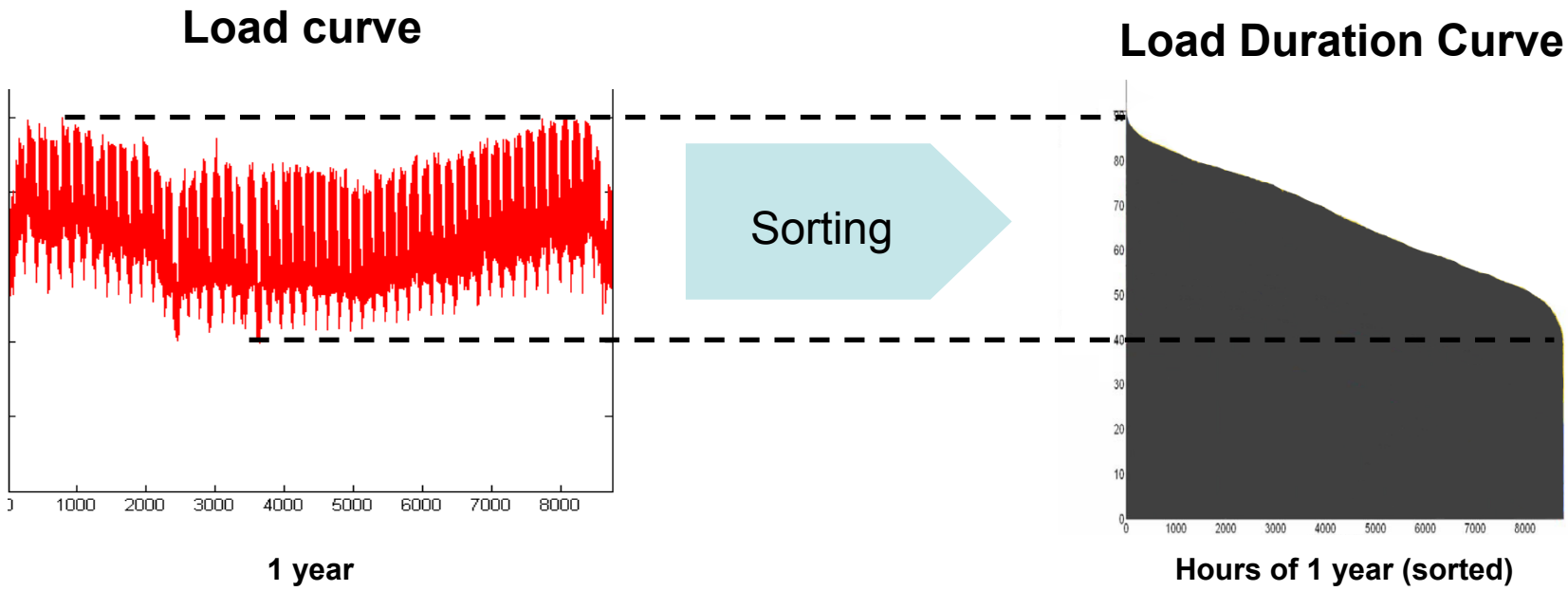
Load Duration Curve needs to be included into the models



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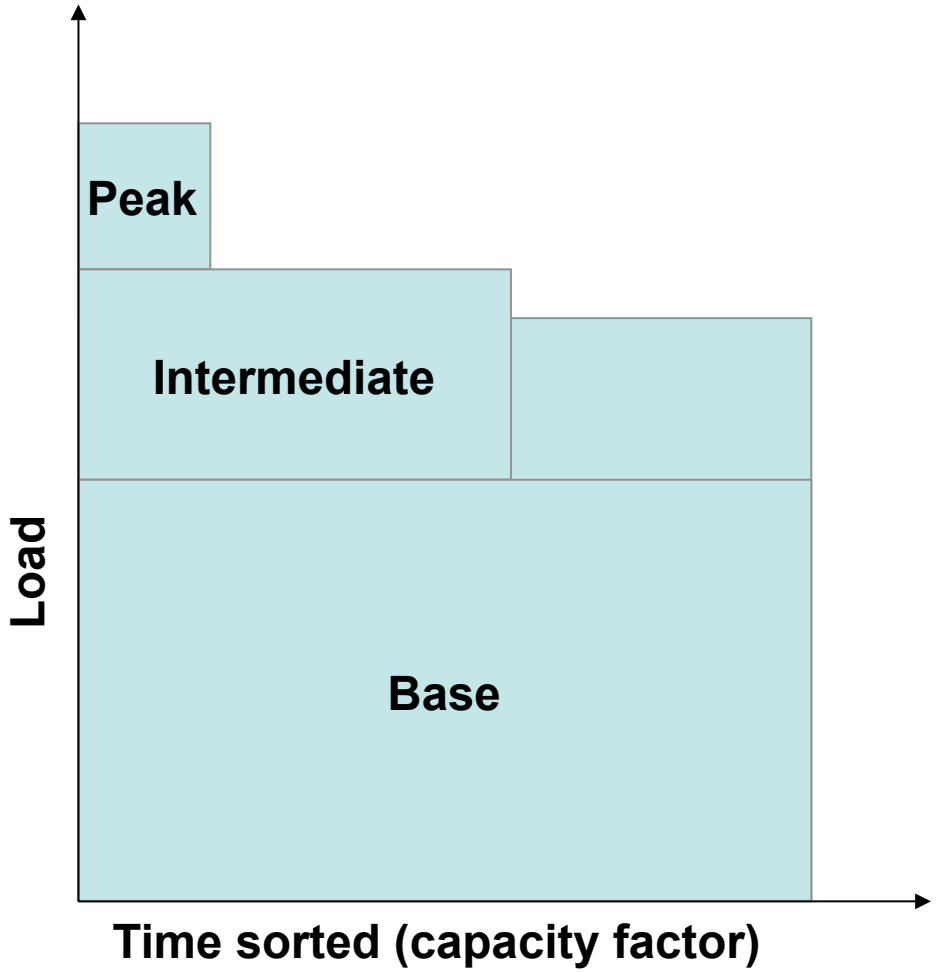
Load Duration Curve is approximated by a step function



Old Remind-D model

- Average load
- Fixed capacity factor (according to the past)

New

- Three load types
- Variable capacity factor

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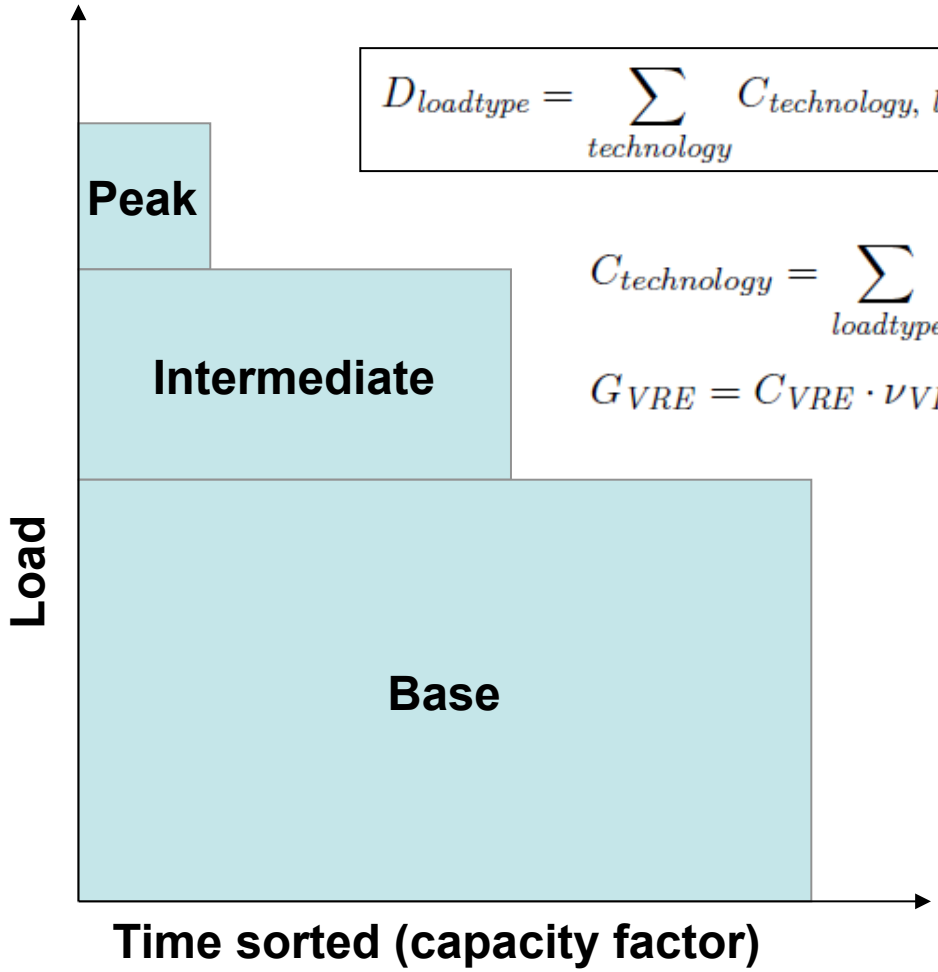

$$D_{loadtype} = \sum_{technology} C_{technology,\ loadtype} \cdot \nu_{loadtype} + G_{VRE,\ loadtype}$$

$$C_{technology} = \sum_{loadtype} C_{technology,\ loadtype}$$

$$G_{VRE} = C_{VRE} \cdot \nu_{VRE} = \sum_{loadtype} G_{VRE,\ loadtype} + G_{VRE,\ curtailed}$$

$loadtype = \{peak, intermediate, base\}$

$technology$: dispatchable technologies (e.g. gas plant, coal plant)

C : nameplate capacity

D : electricity demand

$G_{VRE,\ loadtype}$: generation of variable renewable energy (VRE) in loadtype

ν : full load hours (capacity factor)

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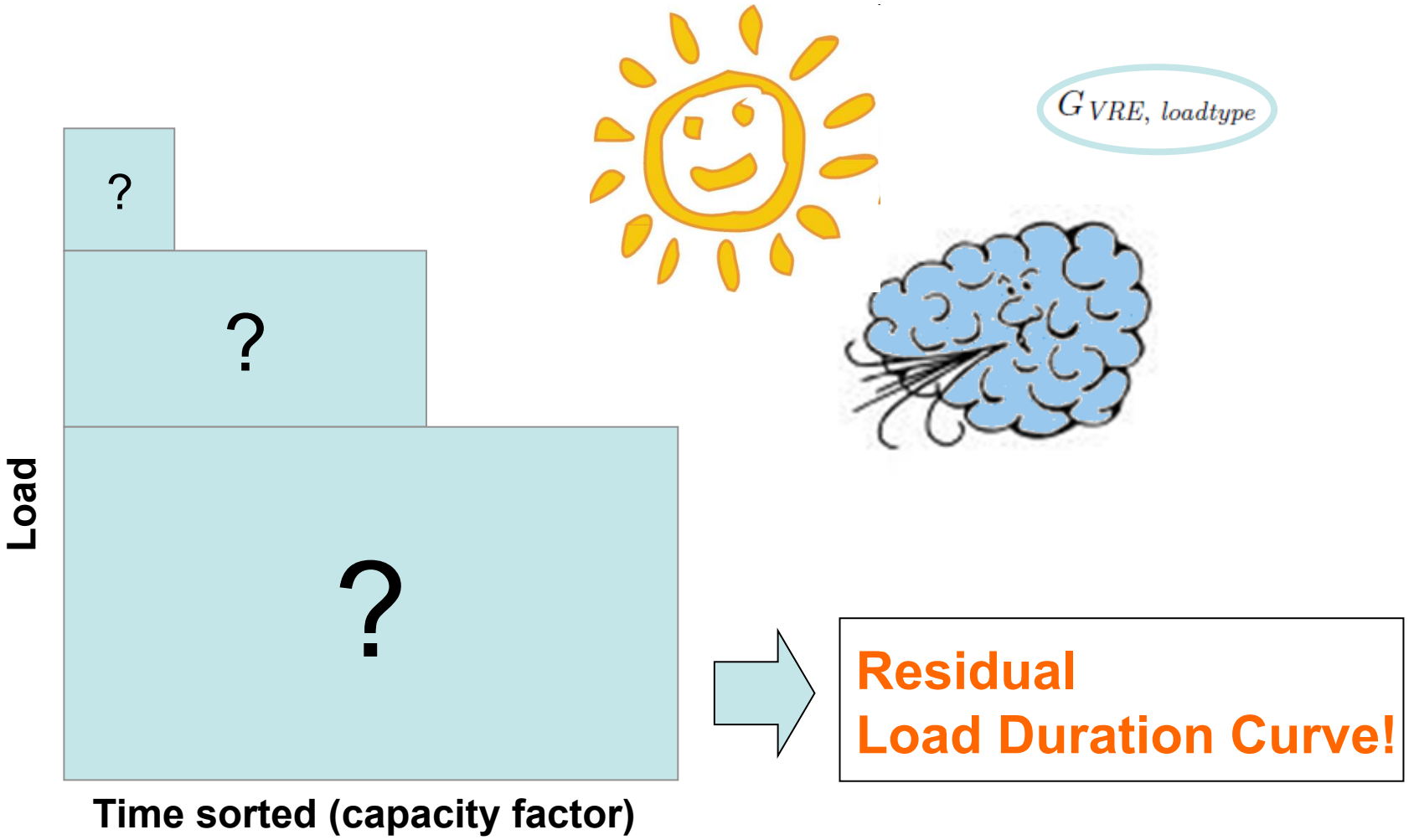
Where does Variable Renewable Energy contribute?



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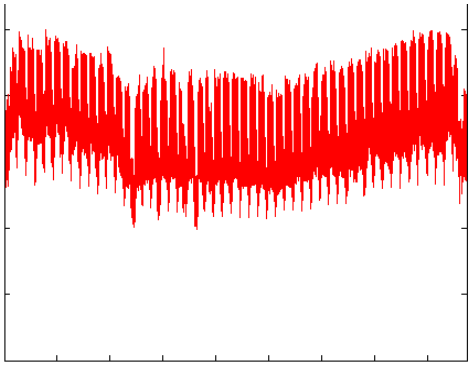
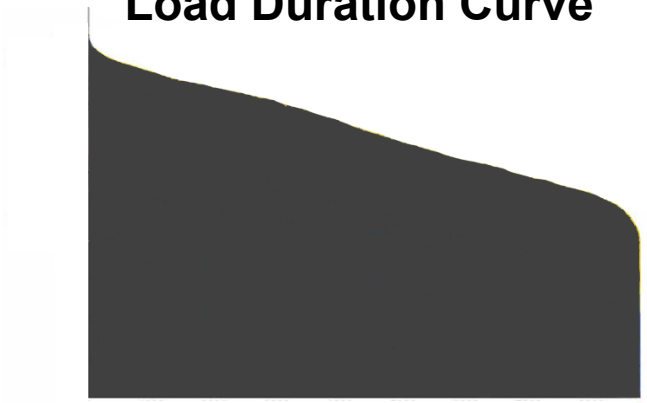
The Residual Load Duration Curve

Load curve



1 year

Load Duration Curve



Time (sorted)

Adapted from Saint-Drenan et al., 2009

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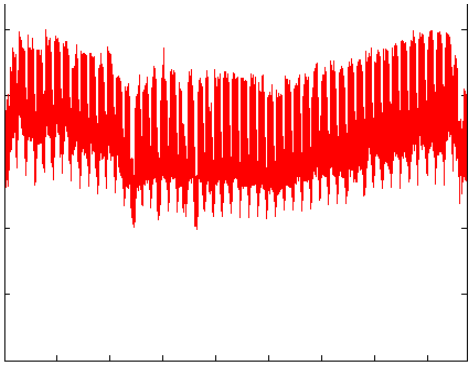

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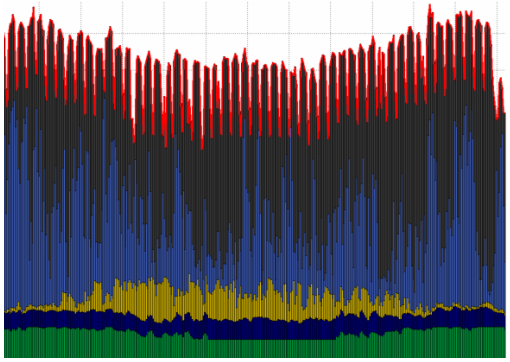
Load and renewables



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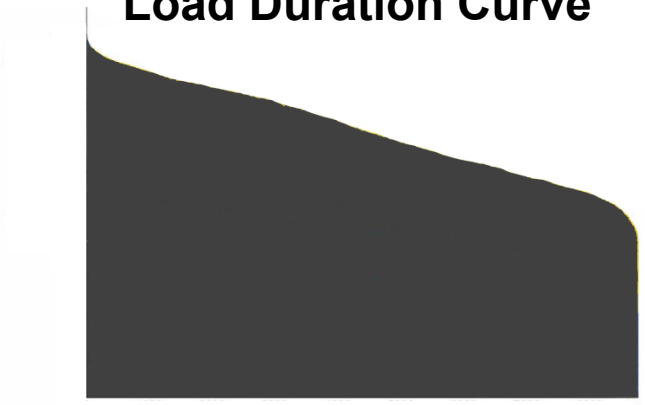

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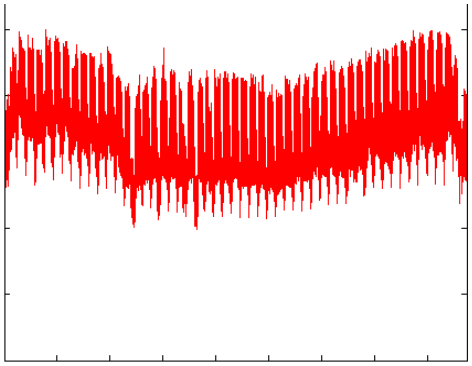

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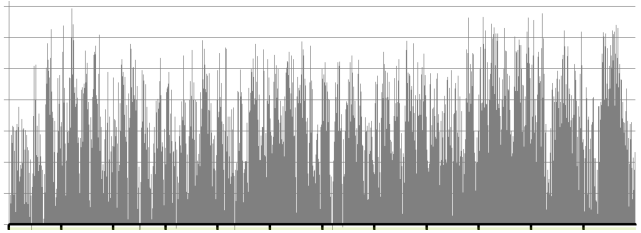

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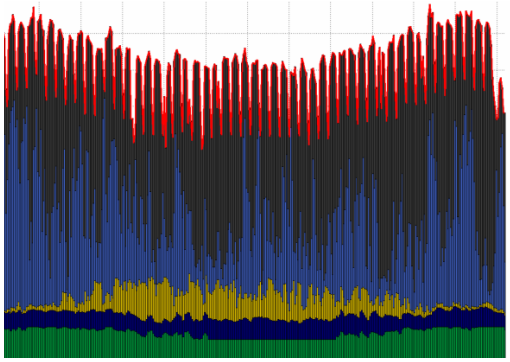

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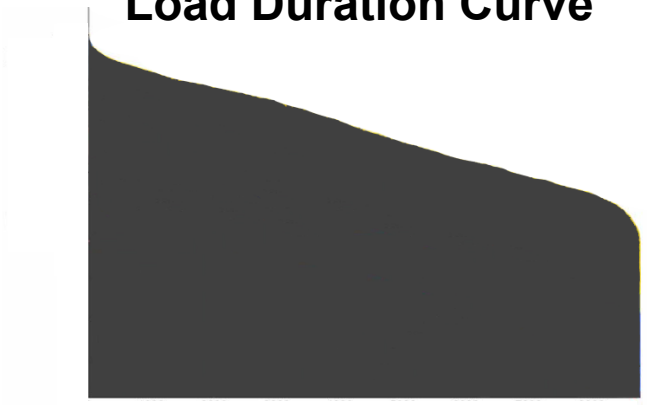

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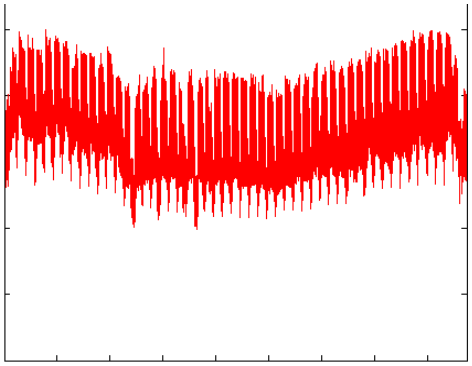

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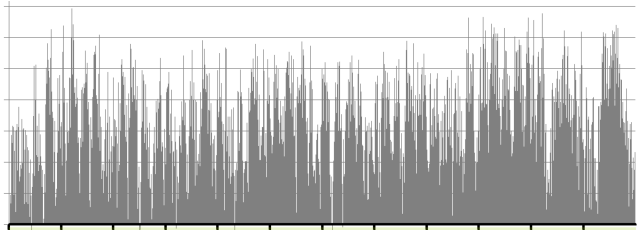

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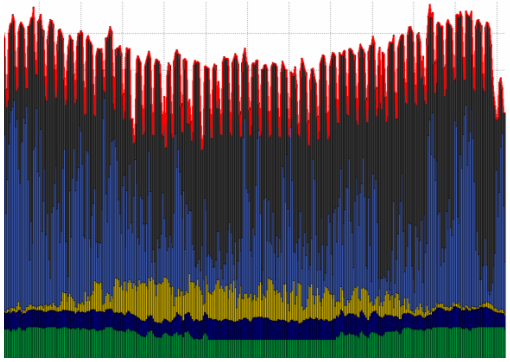

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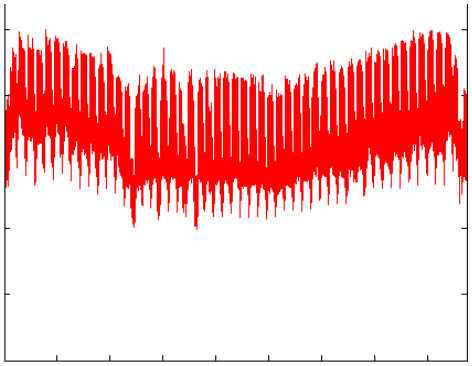

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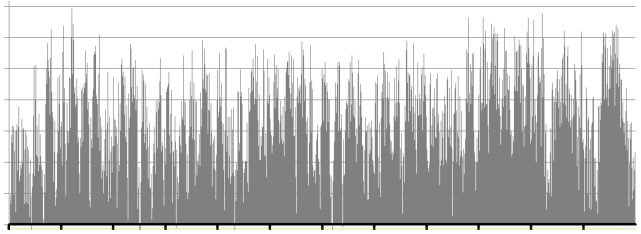

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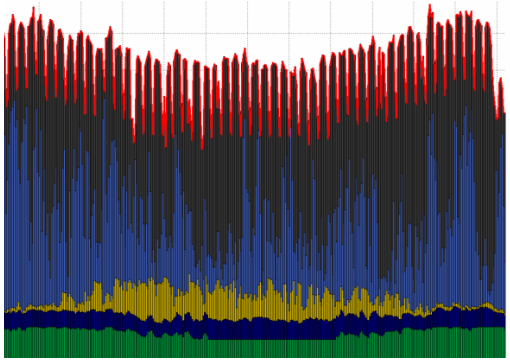

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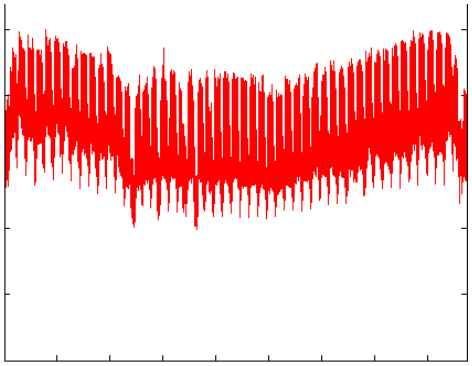

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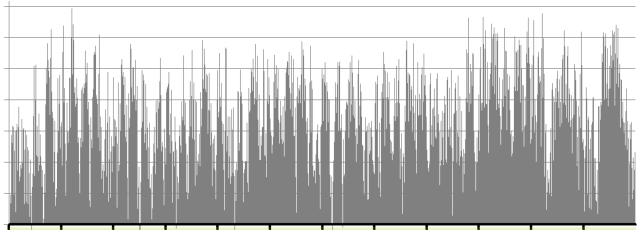

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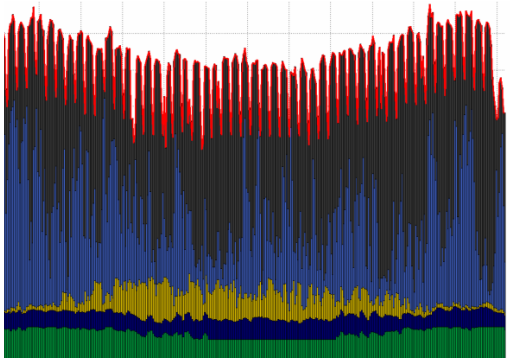

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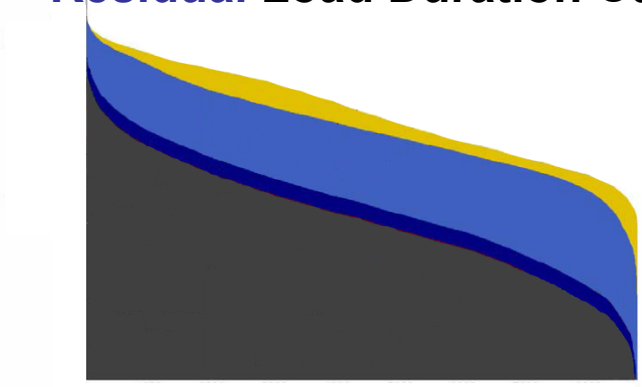

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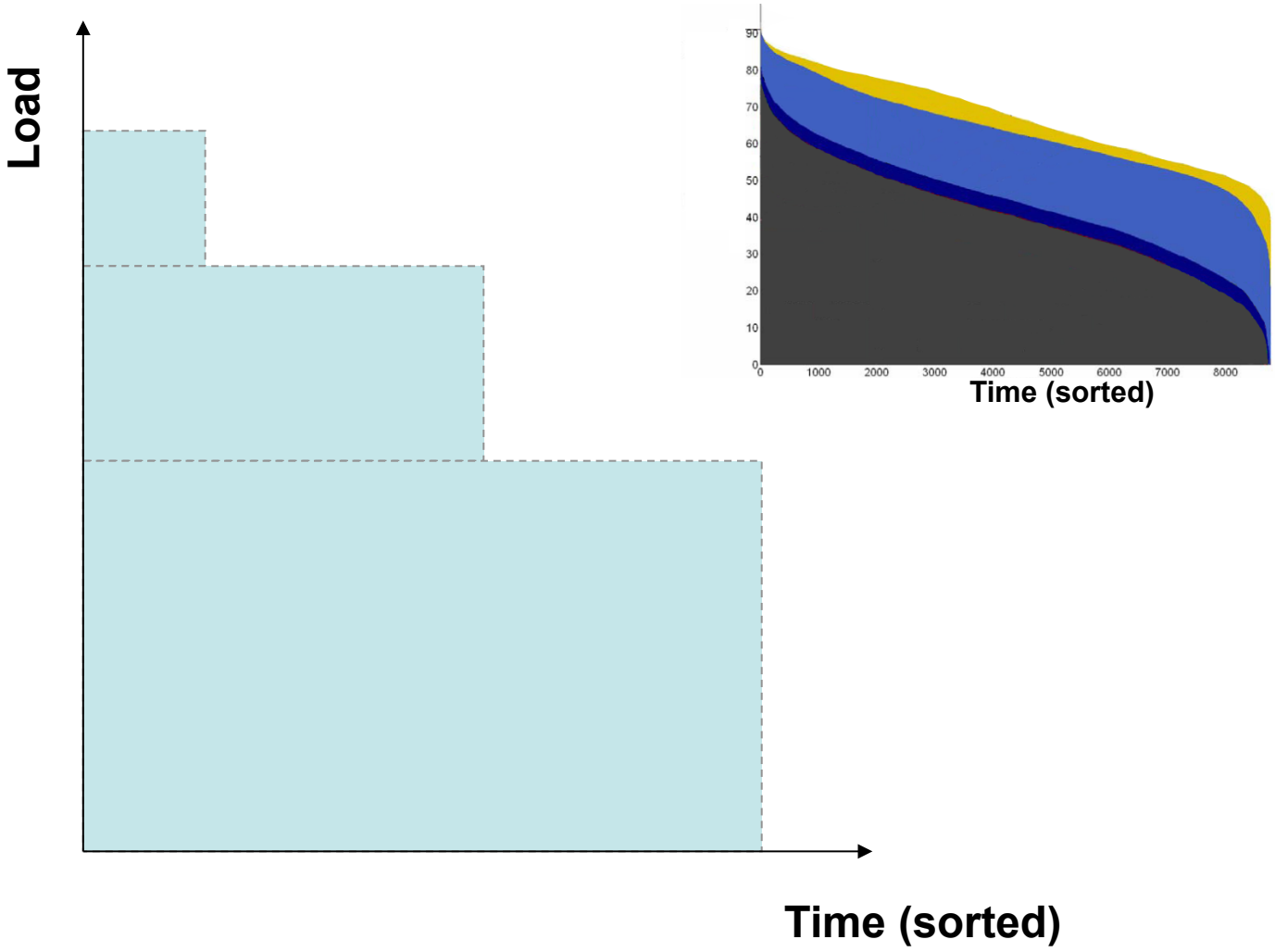
How to account for the Residual Load Duration Curve in the REMIND model?



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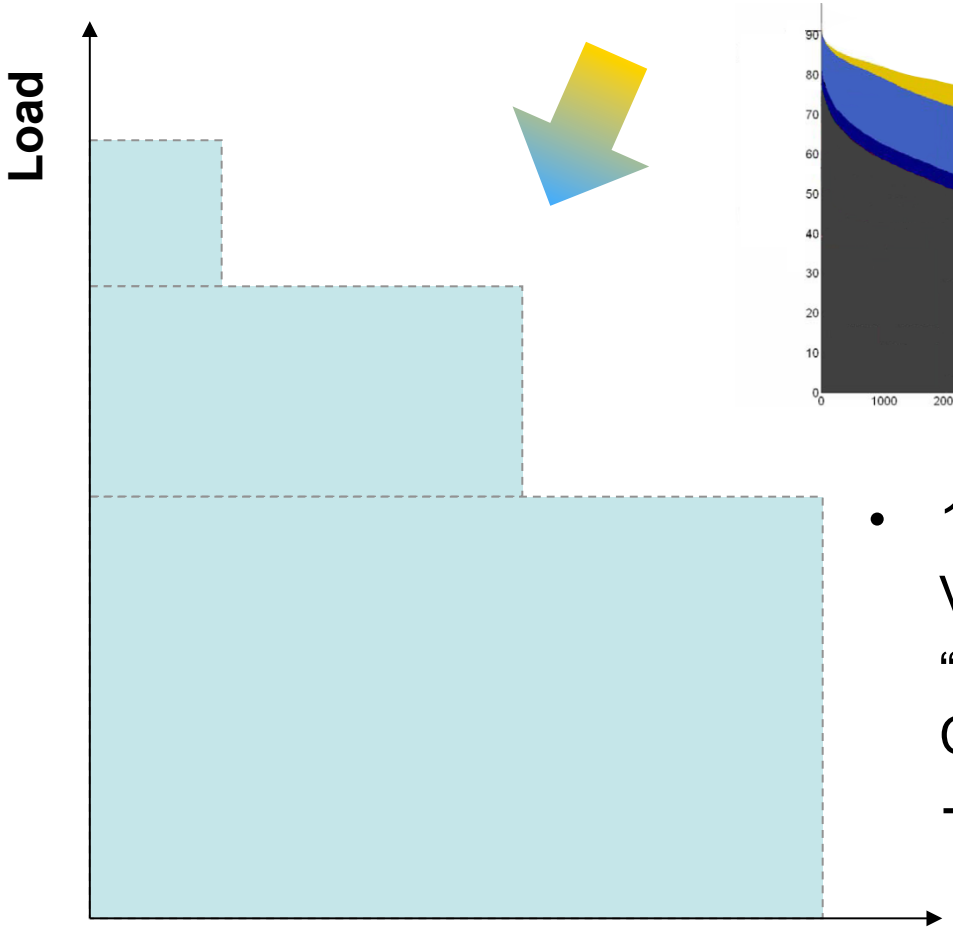

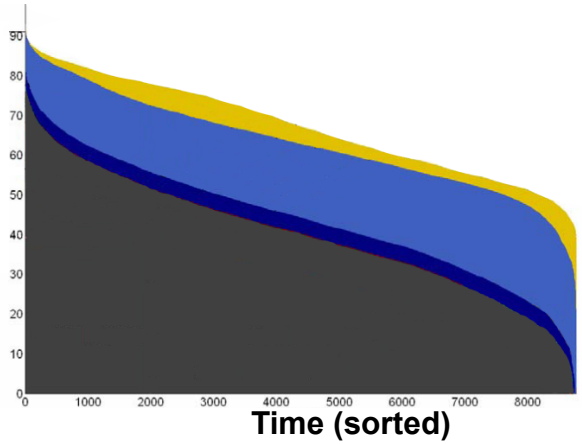

- 1st approximation:
  Variable Renewable Energy "pushes" the Load Duration Curve sidewards
  → New boxes

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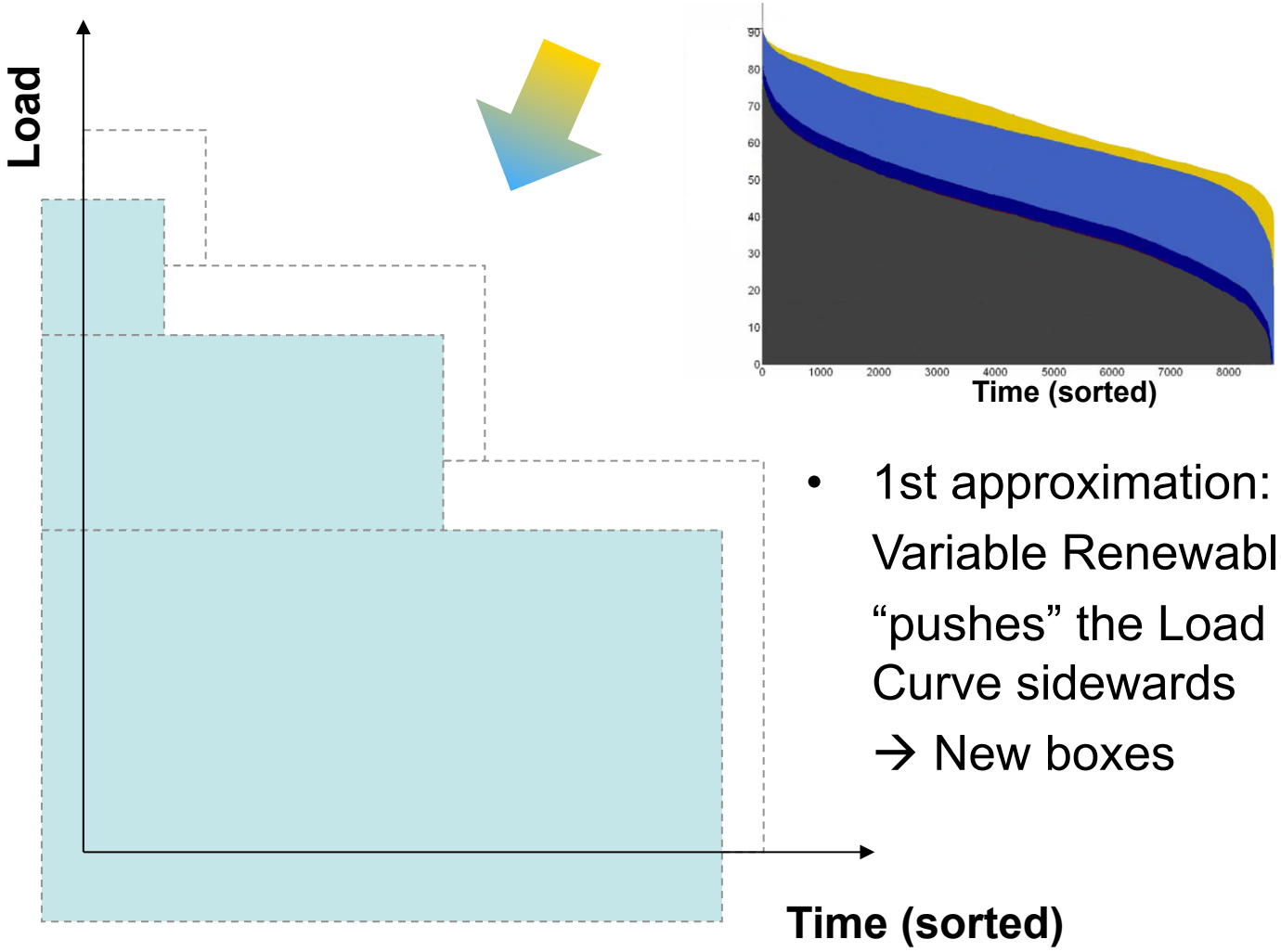

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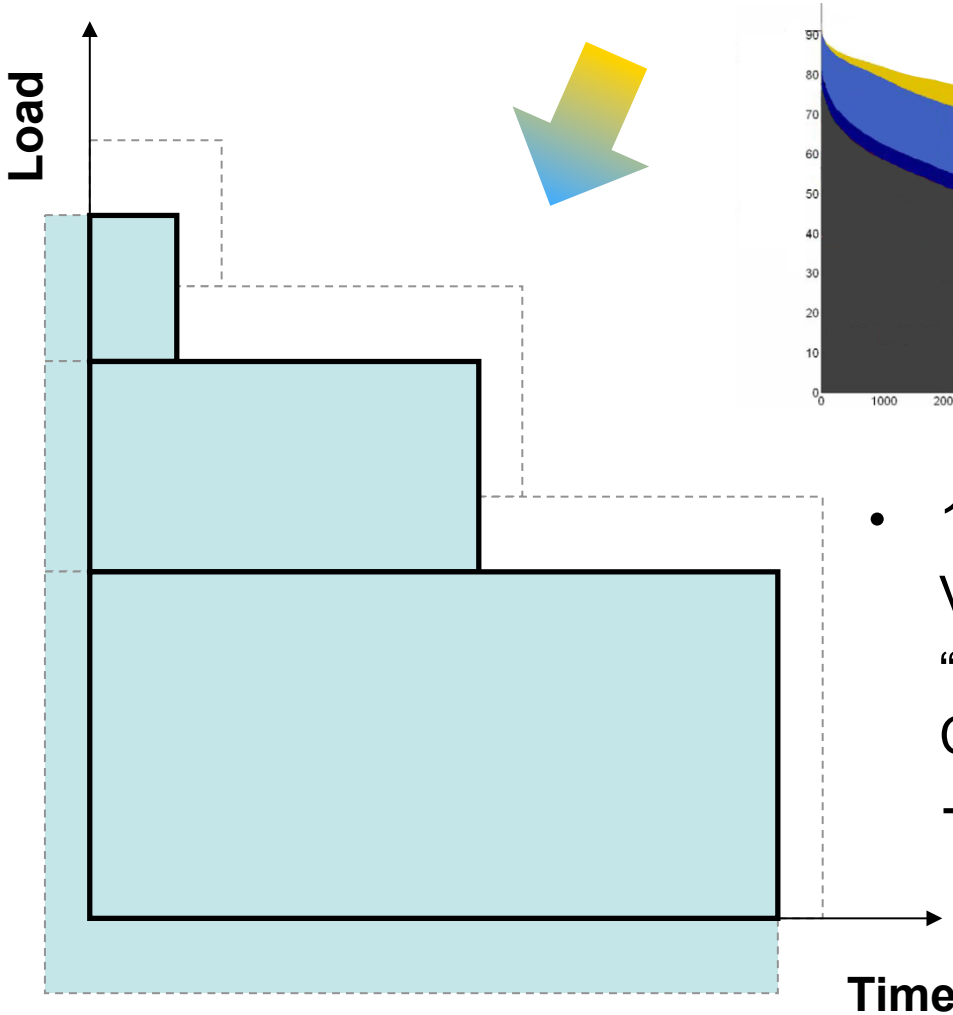

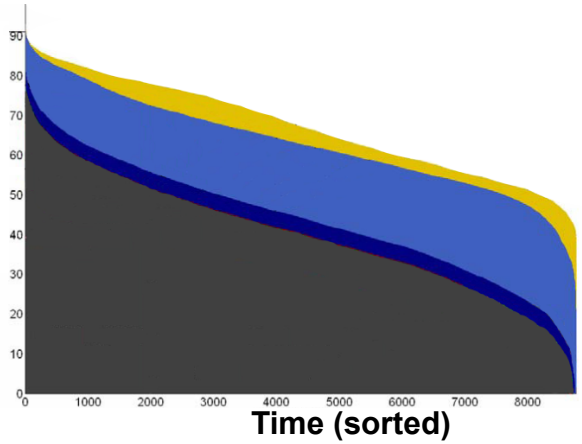

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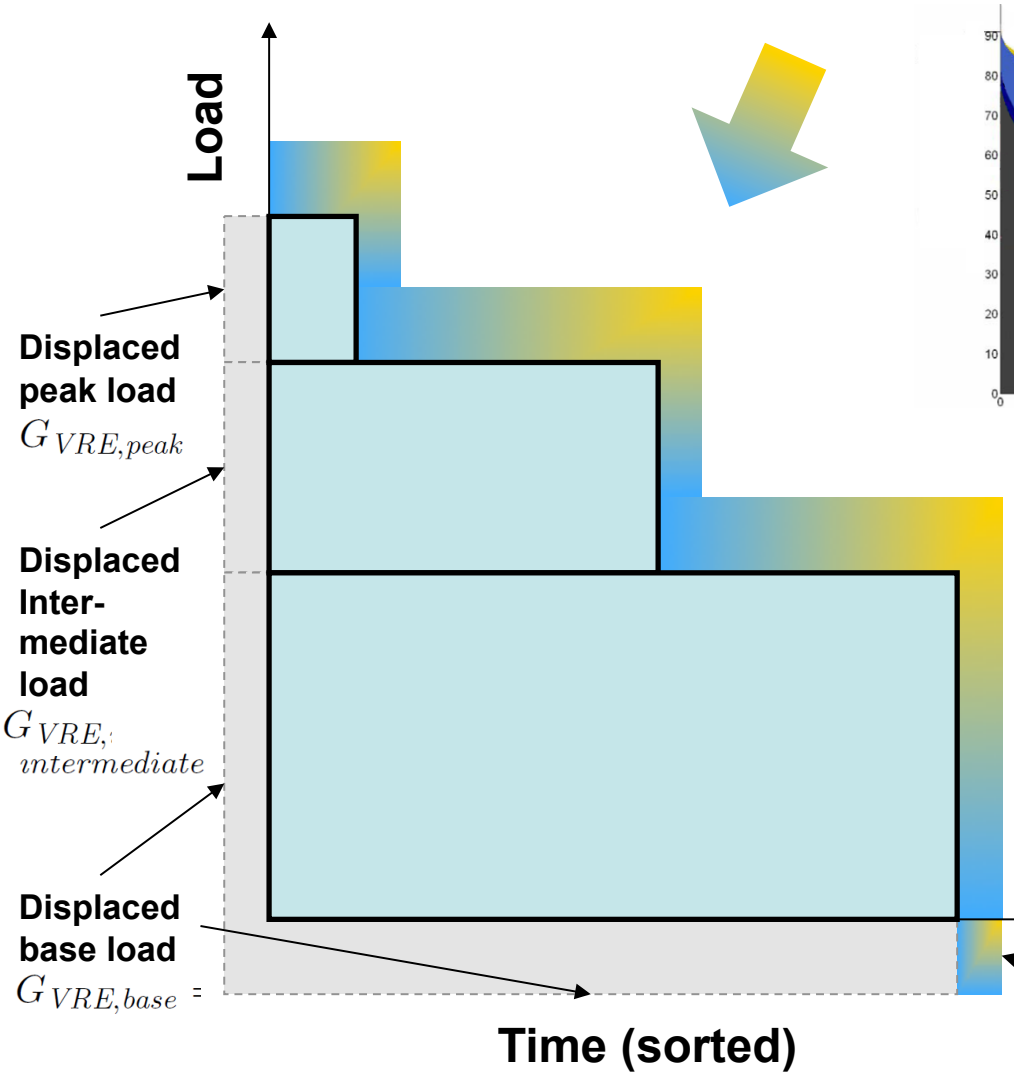

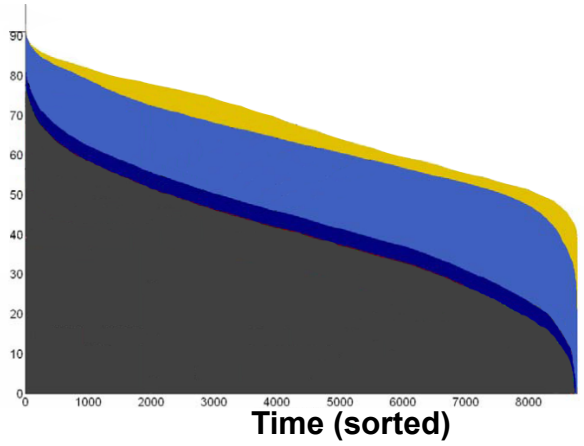

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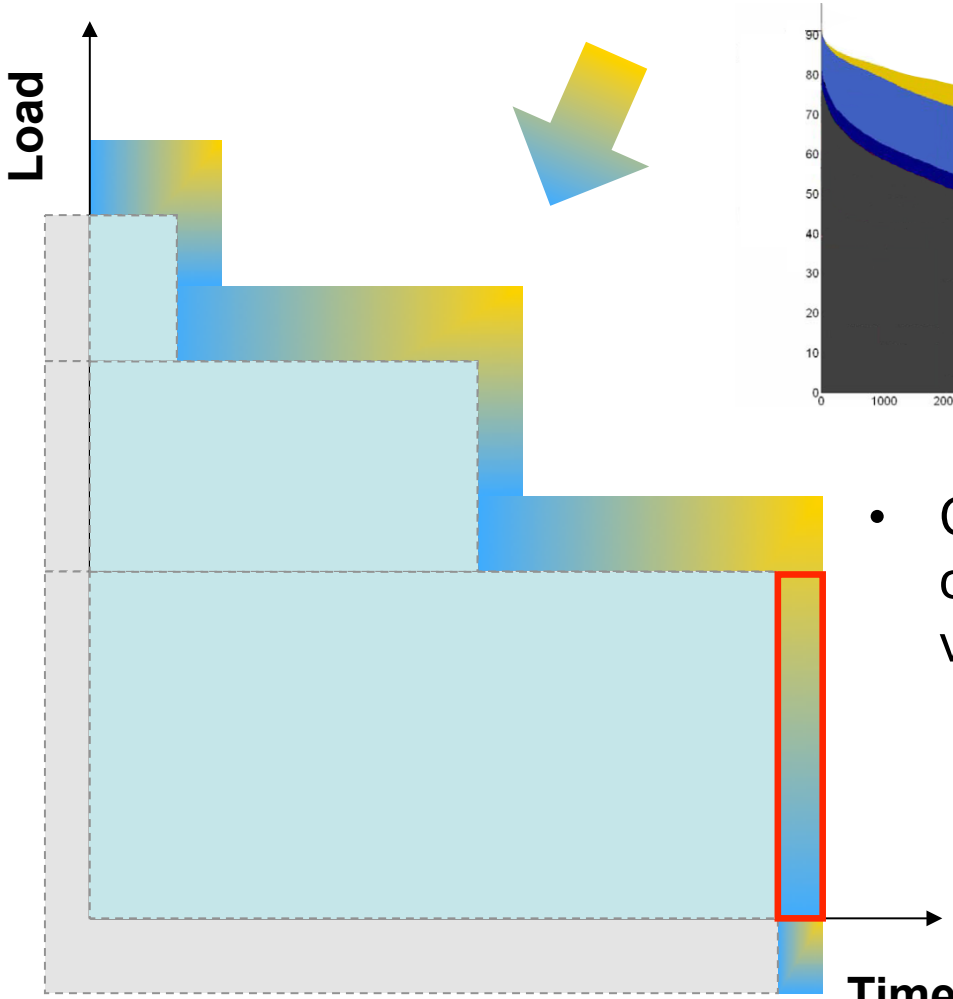

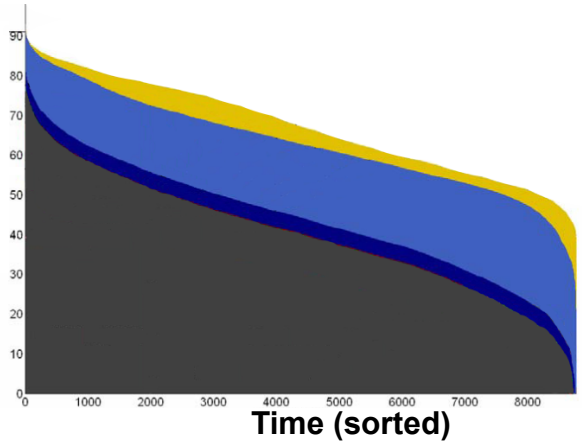

- Capacity factors of dispatchable capacities decrease (if no voluntary curtailment)

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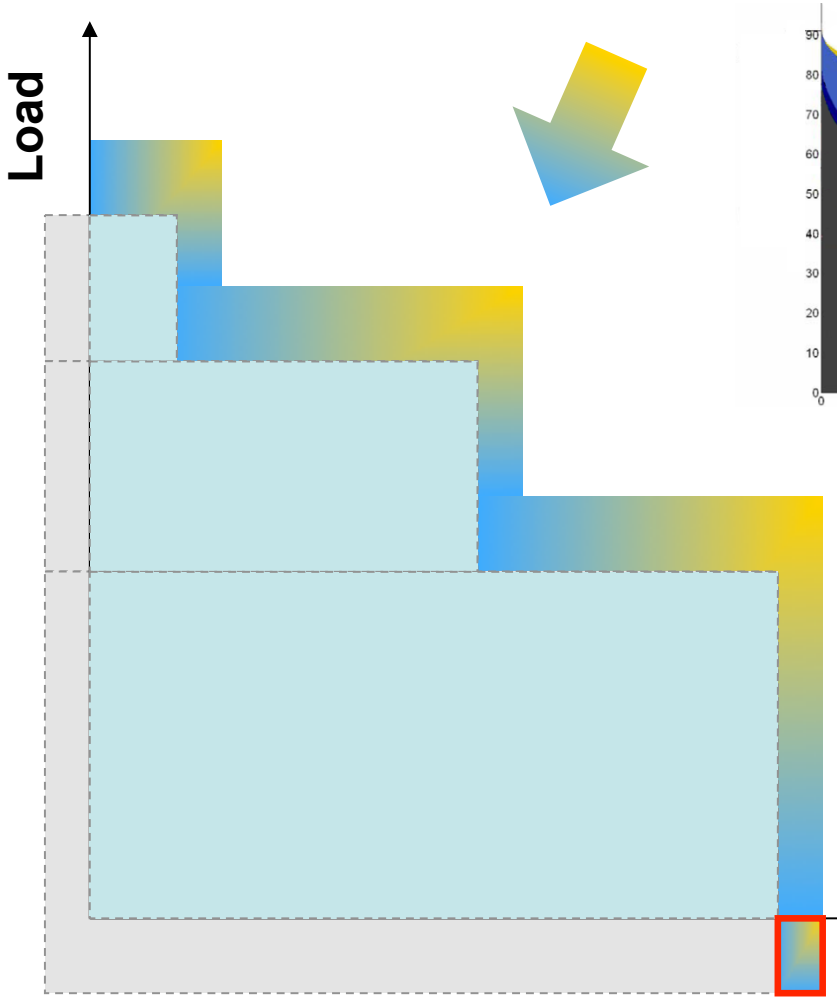

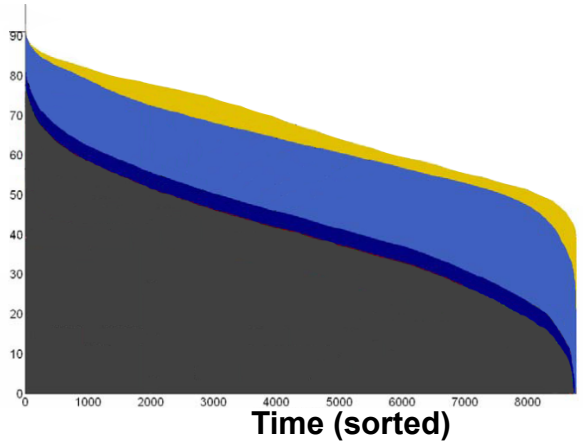

- Capacity factors of dispatchable capacities decrease (if no voluntary curtailment)
- Forced curtailment is accounted for

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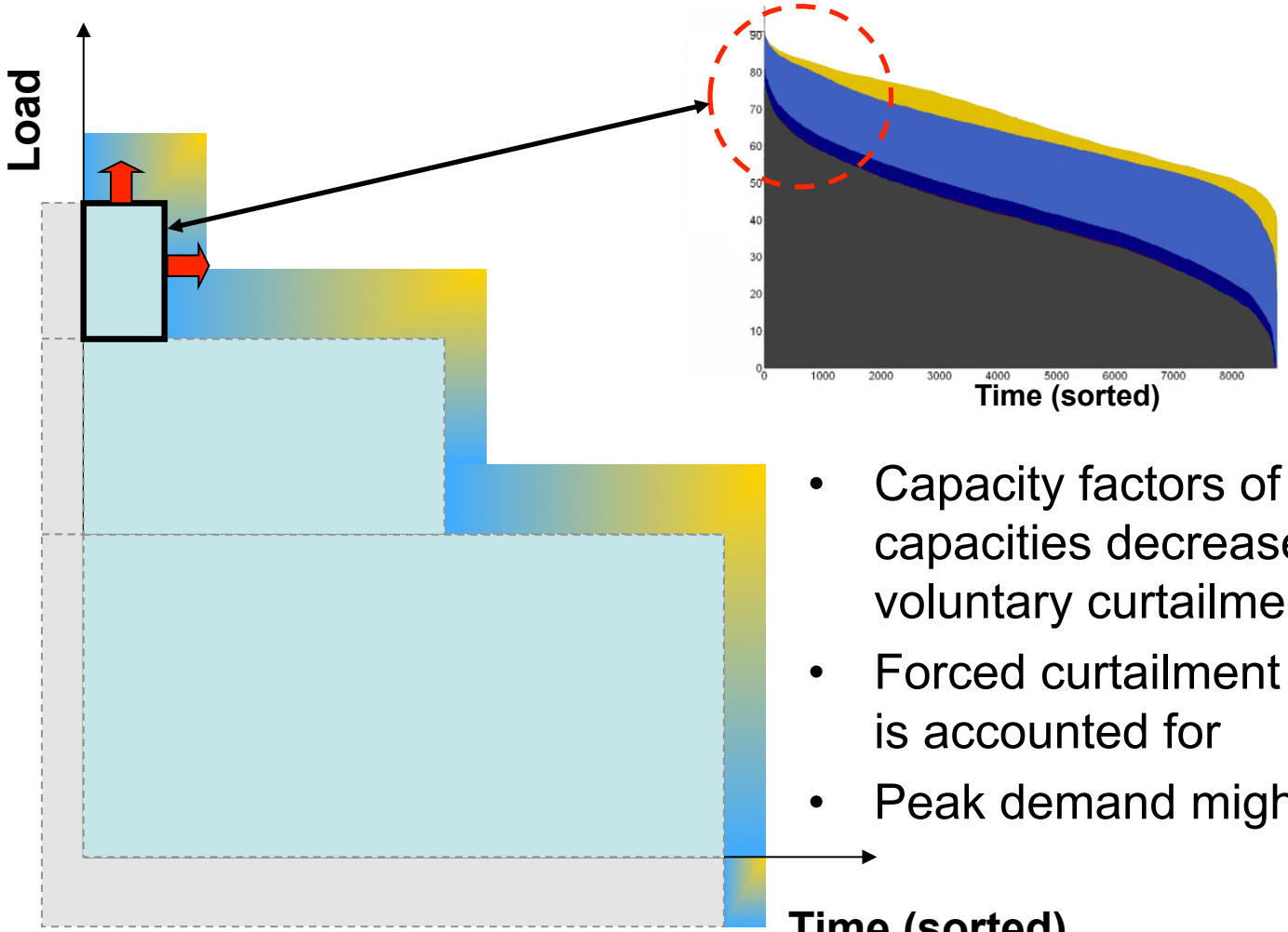

- Capacity factors of dispatchable capacities decrease (if no voluntary curtailment)
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- Peak demand might increase

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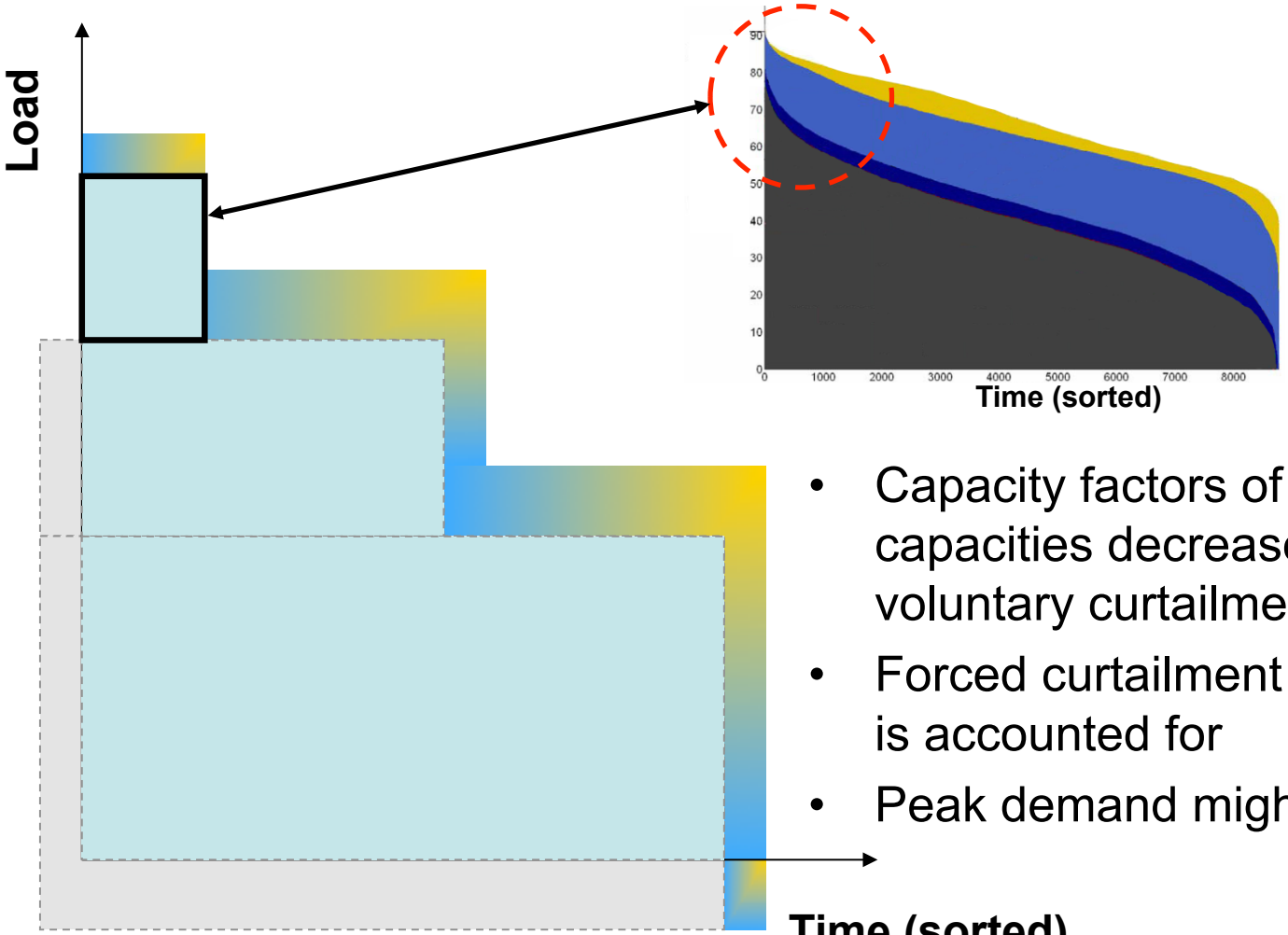

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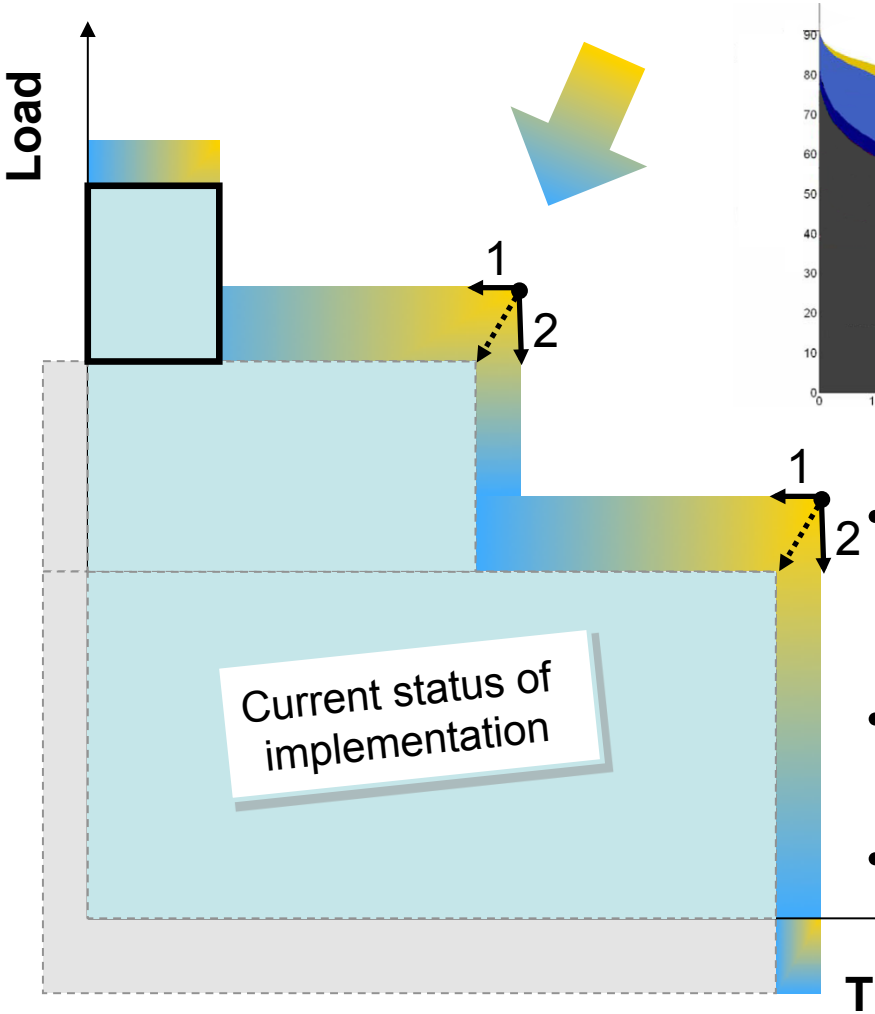

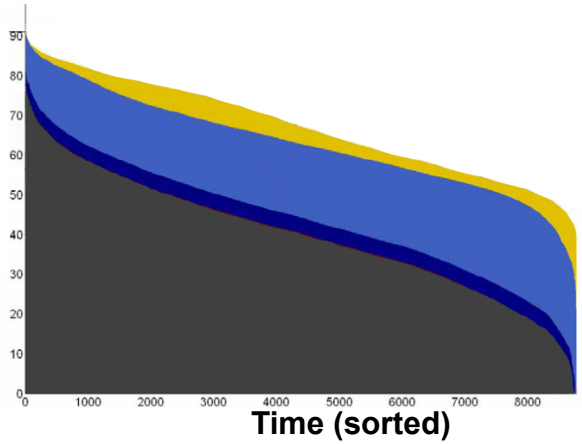

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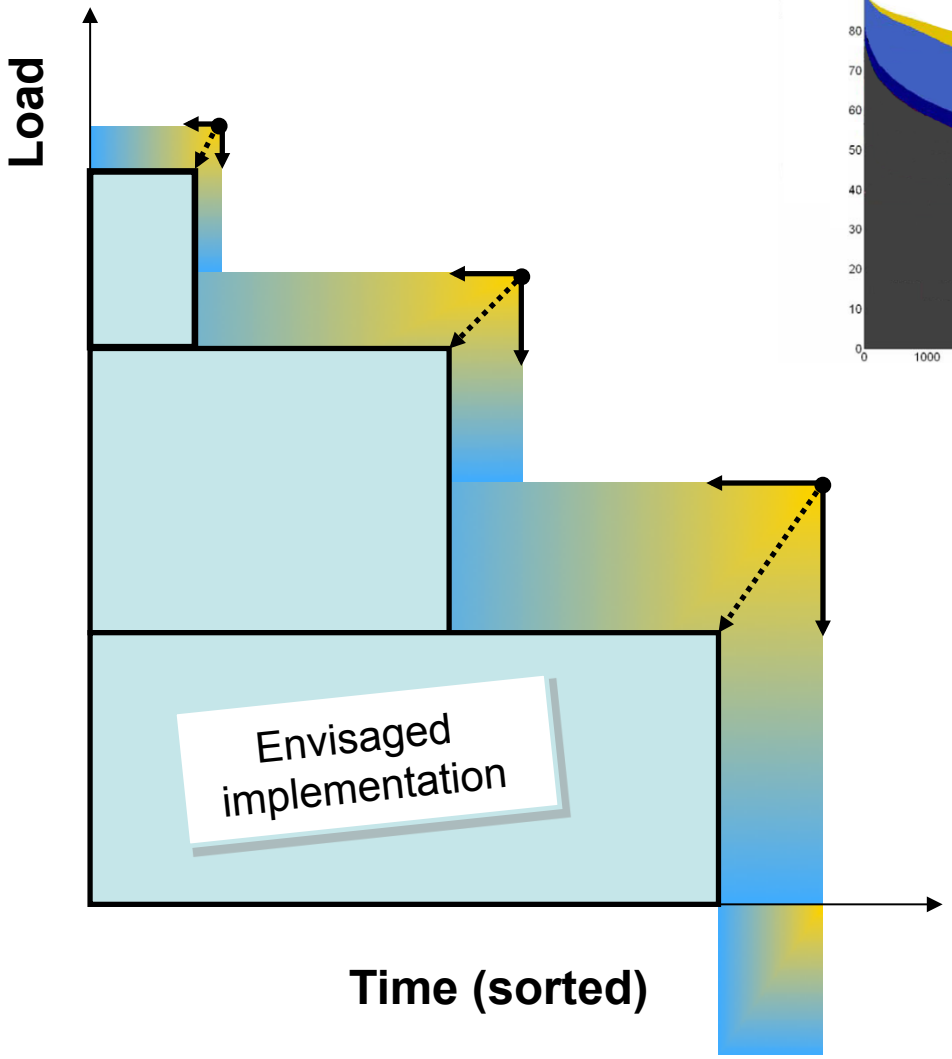

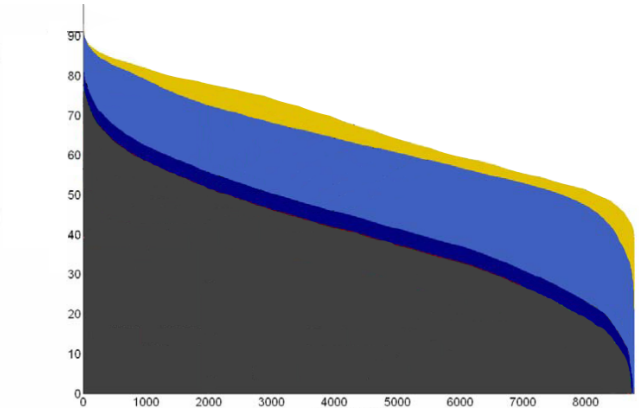

A detailed parameterization will be derived from data:

Different „directions“ depending on

- Loadtype
- Type of variable renewable energy
- Penetration level
- Renewable mix (Correlations)
- Region (Remind-R)

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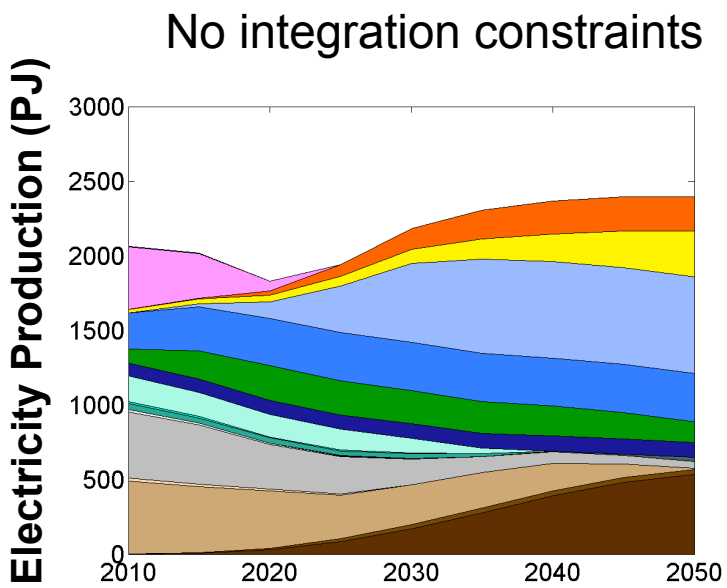
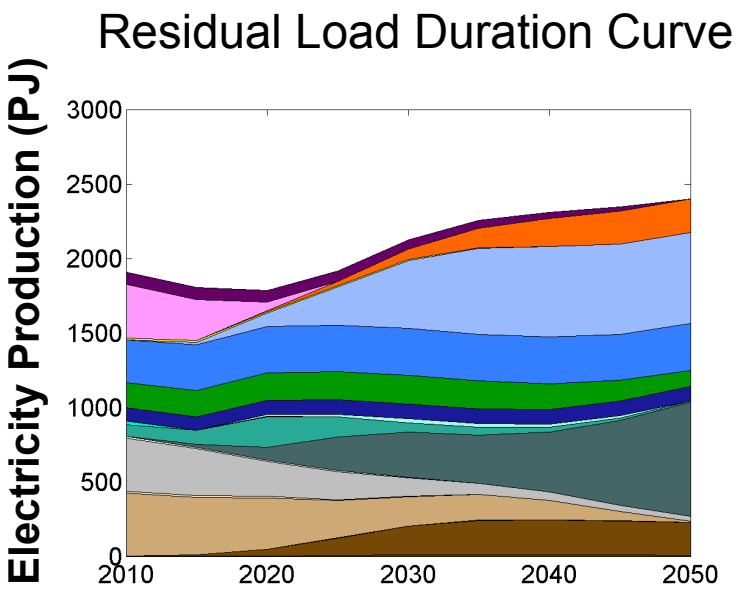
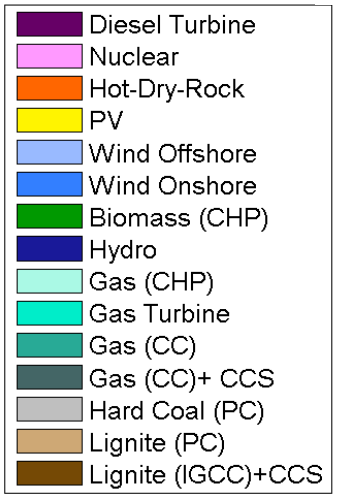
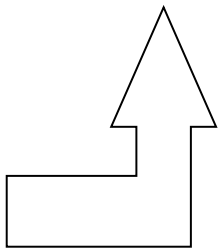
Intermediate result with Residual Load Duration Curve







- More Gas (CC) + CCS
- No PV anymore
- Less Lignite (CCS)



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Operating reserve constraints – flexibility coefficients are estimated

$$\alpha_{loadtype} D_{loadtype} + \sum_{VRE} \alpha_{VRE} G_{VRE,\ loadtype} + \sum_{dispatchable} \alpha_{dispatchable} G_{dispatchable,\ loadtype} \geq 0$$

$G_{dispatchable,\ loadtype}$: Generation from dispatchable plants in loadtype

$\alpha_{VRE}, \alpha_{dispatchable}$: Coefficients could be differentiated for different loadtypes in a more detailed representation

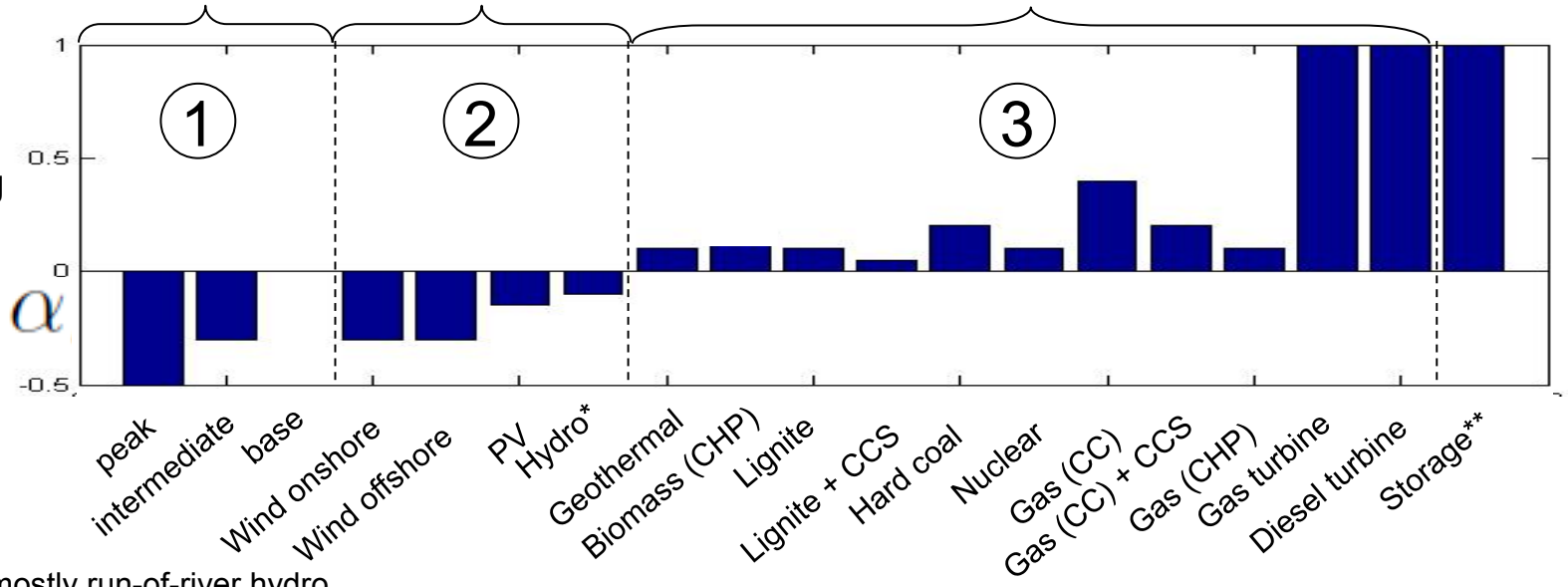
$$loadtype = \{peak, intermediate, base\}$$

1) Variable load
increase requirement dependent on load type

2) Variable renewable energy (VRE)
increase requirement

3) Dispatchable plants
contribute to meeting requirement

Coefficients for operating reserve constraint



* In Germany mostly run-of-river hydro
** Storage not implemented yet

Based on Patrick Sullivan's implementation in the MESSAGE model

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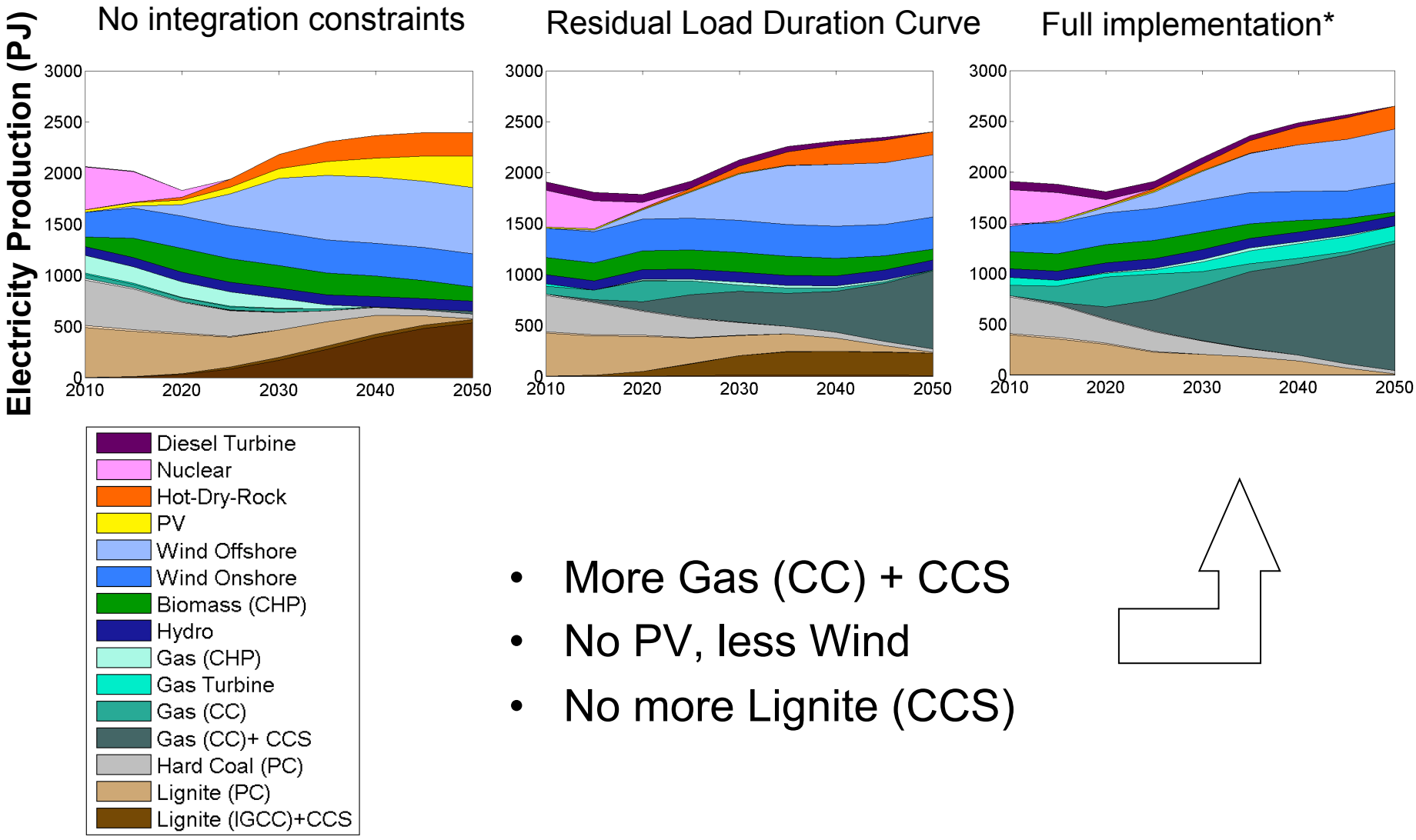
Full implementation: Reduced use of variable renewable energy. Gas (CCS) is substituting lignite (CCS)



- More Gas (CC) + CCS
- No PV, less Wind
- No more Lignite (CCS)

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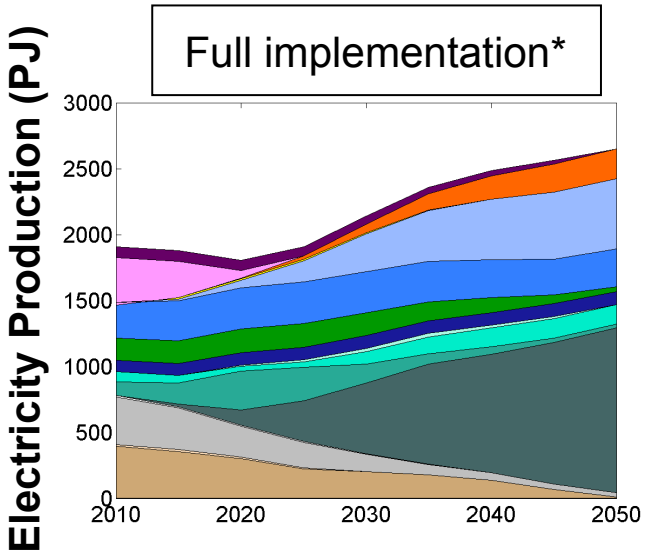
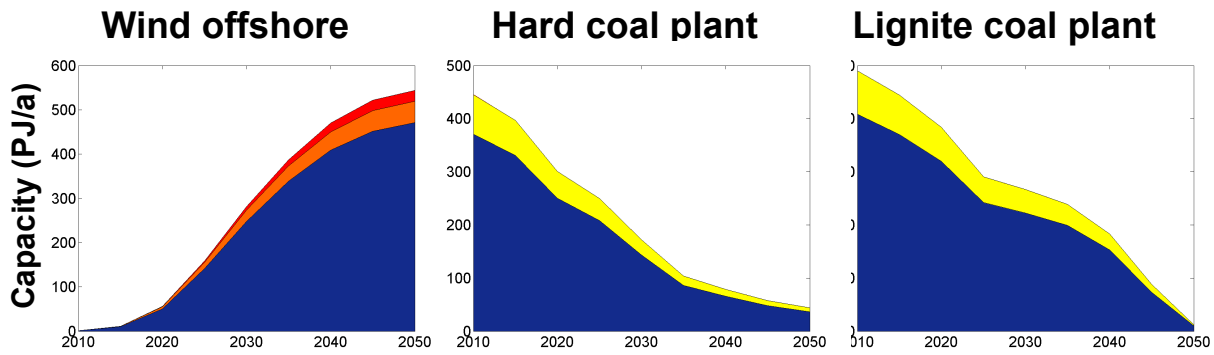
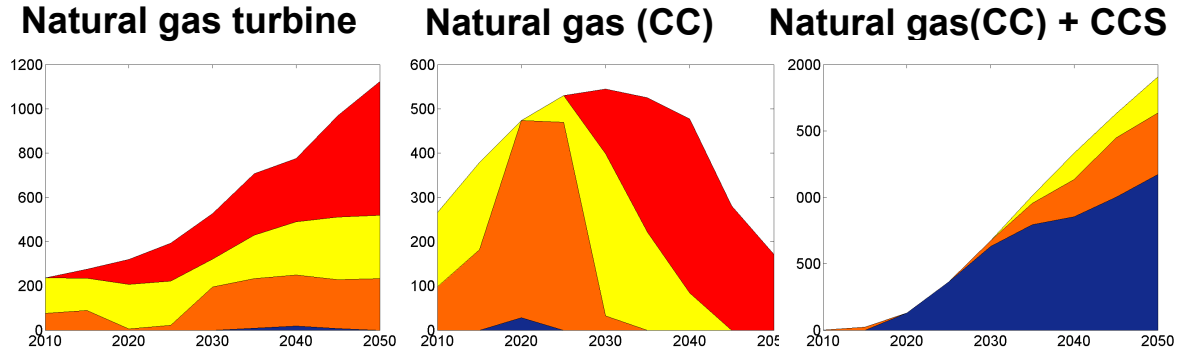
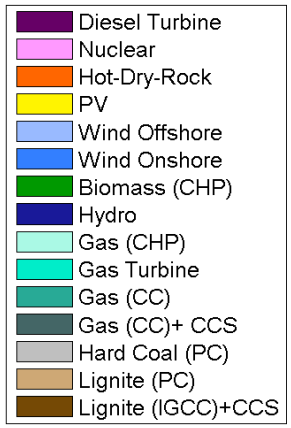
* Full implementation contains Residual Load Duration Curve, Operating and Planning reserves

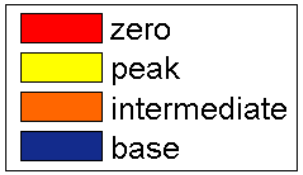
Details on the use of different capacities in the loadtypes

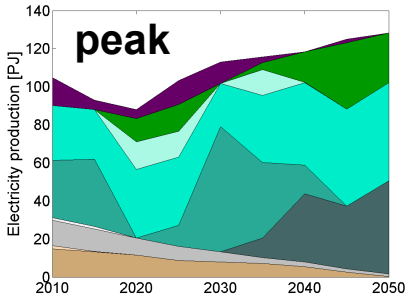


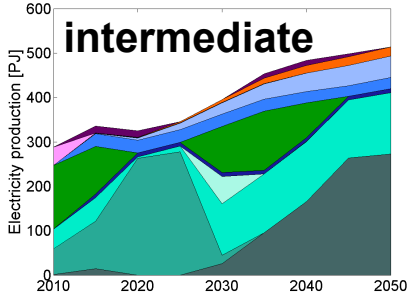


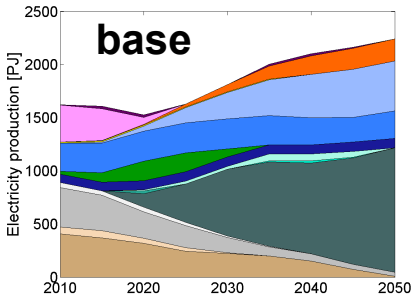












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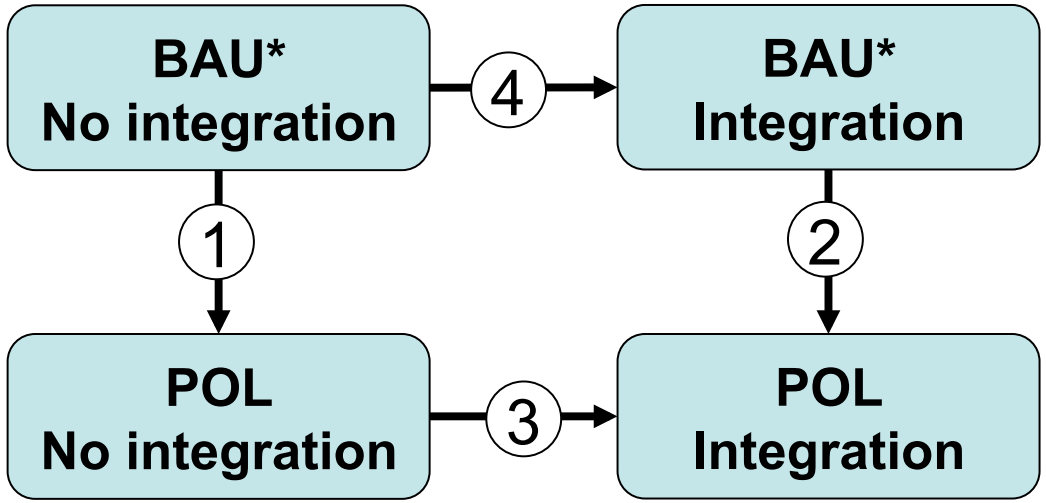
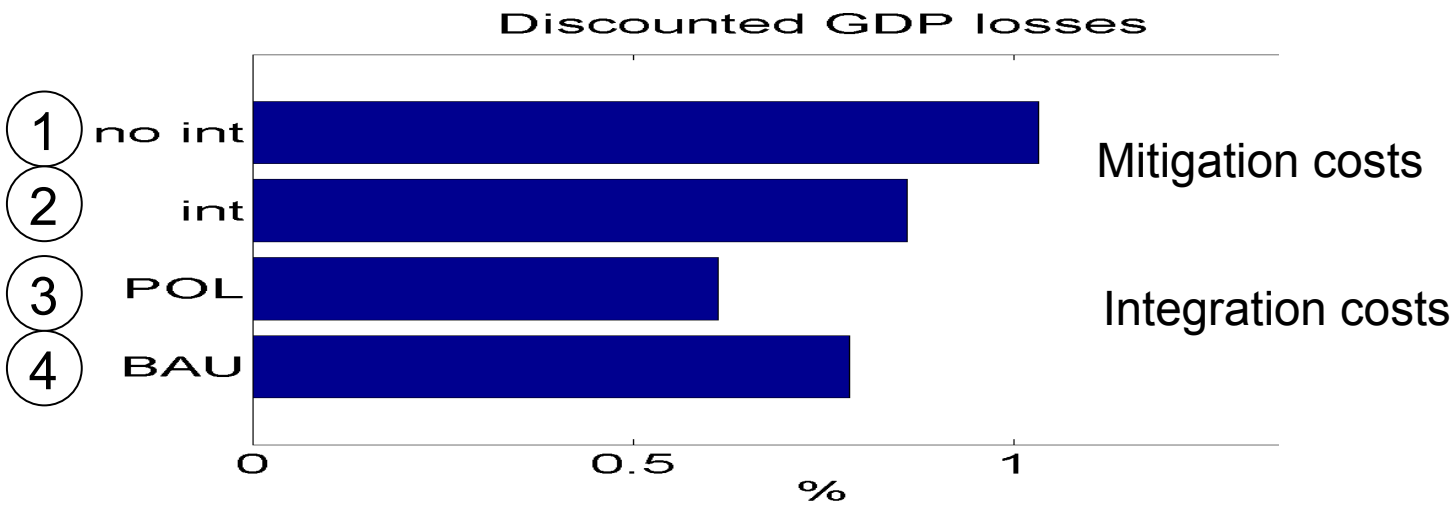
* Full implementation contains Residual Load Duration Curve, Operating and Planning reserves

Integration and mitigation costs are comparable

Preliminary results

* BAU: Already contains some climate policy: ~35% reduction 2050 (1990) and carbon budget of 30GtCO$_2$ (2010-2050)





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Thank you!

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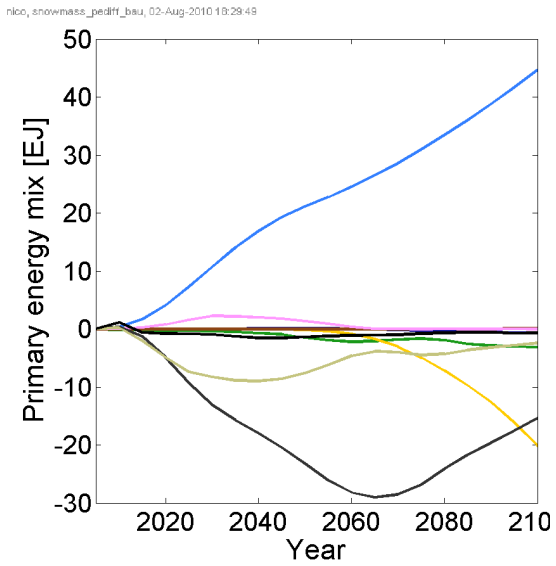
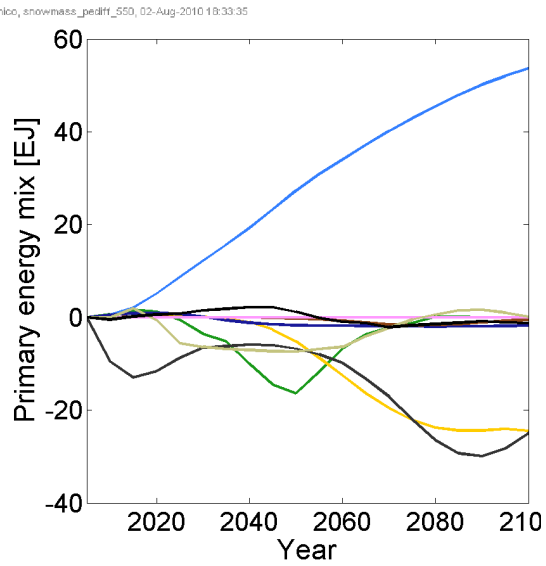
Backup Slides

Differences at the global level – old vs. mew

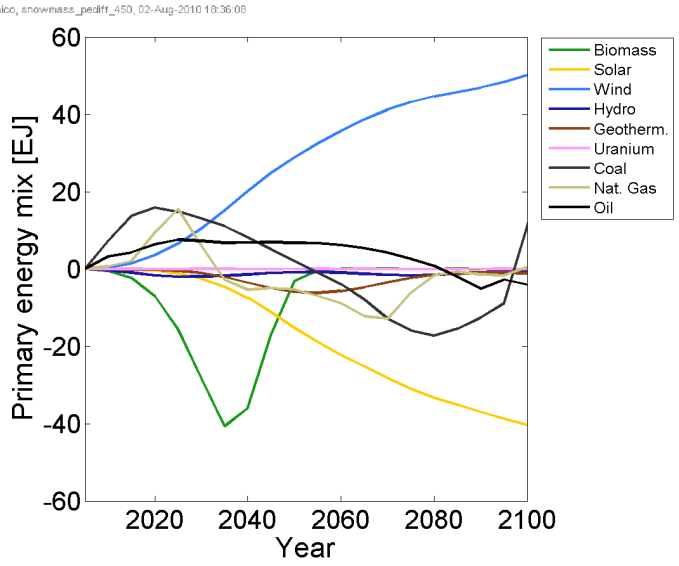
BAU



550ppm



450ppm



➔ 550 ppm: less gas & coal used

➔ 450 ppm: initially more gas and coal used

Reason might be that higher wind potentials allow deeper emission reduction at low costs in the long run and hence higher emissions in the short run

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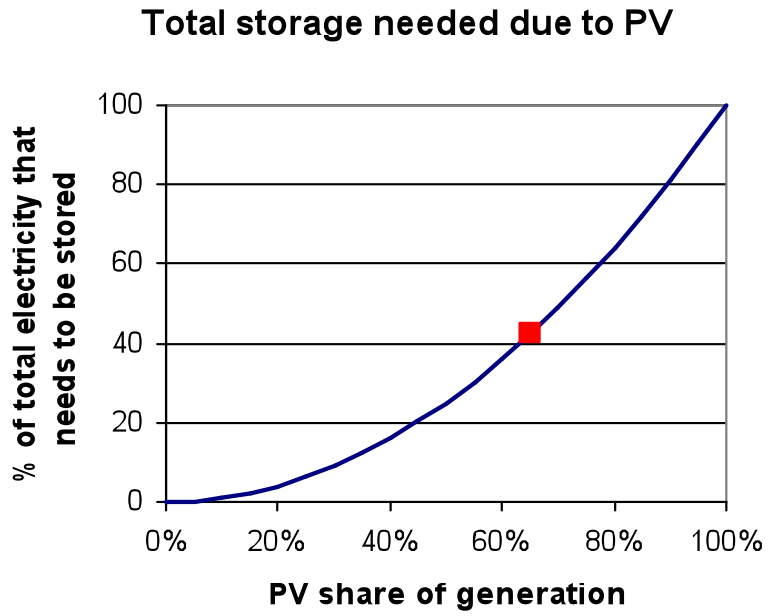
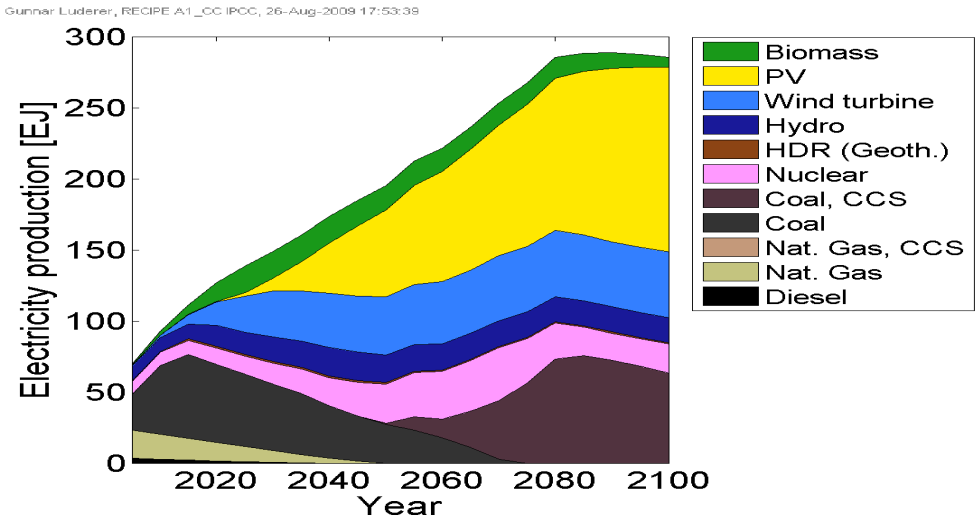
Balancing fluctuations of RETs

- Storage requirement per installed capacity for each technology depends on the share of generation
- Storage parameterized for three time scales (daily, weekly, seasonal). Flow batteries and pump storage are used for daily and weekly fluctuations.
- Resulting average cost penalties due to investment into storage capacities and storage losses:

Investment costs [USD/kWp]

	in 2050	
PV:	830	➔ 1140-1360
Wind:	890	➔ 1000-1270
	in 2075	
PV:	760	➔ 1030-1340
Wind:	890	➔ 970-1210





Reference for techno-economic parameters of storage: Chen, H., et al. (2009) Progress in Natural Science 19, 291-312

REMIND-D: Coupled energy-system and macroeconomy model for Germany

- Growth model (Ramsey-type)
- Time horizon 2005-2100, 5-year (investment) resolution
- Intertemporal welfare maximization
  - „First best solution“ including perfect foresight
- Full technology flexibility for mitigation
- Only domestic mitigation options
  - no emissions trading
  - only domestic renewable energy potentials

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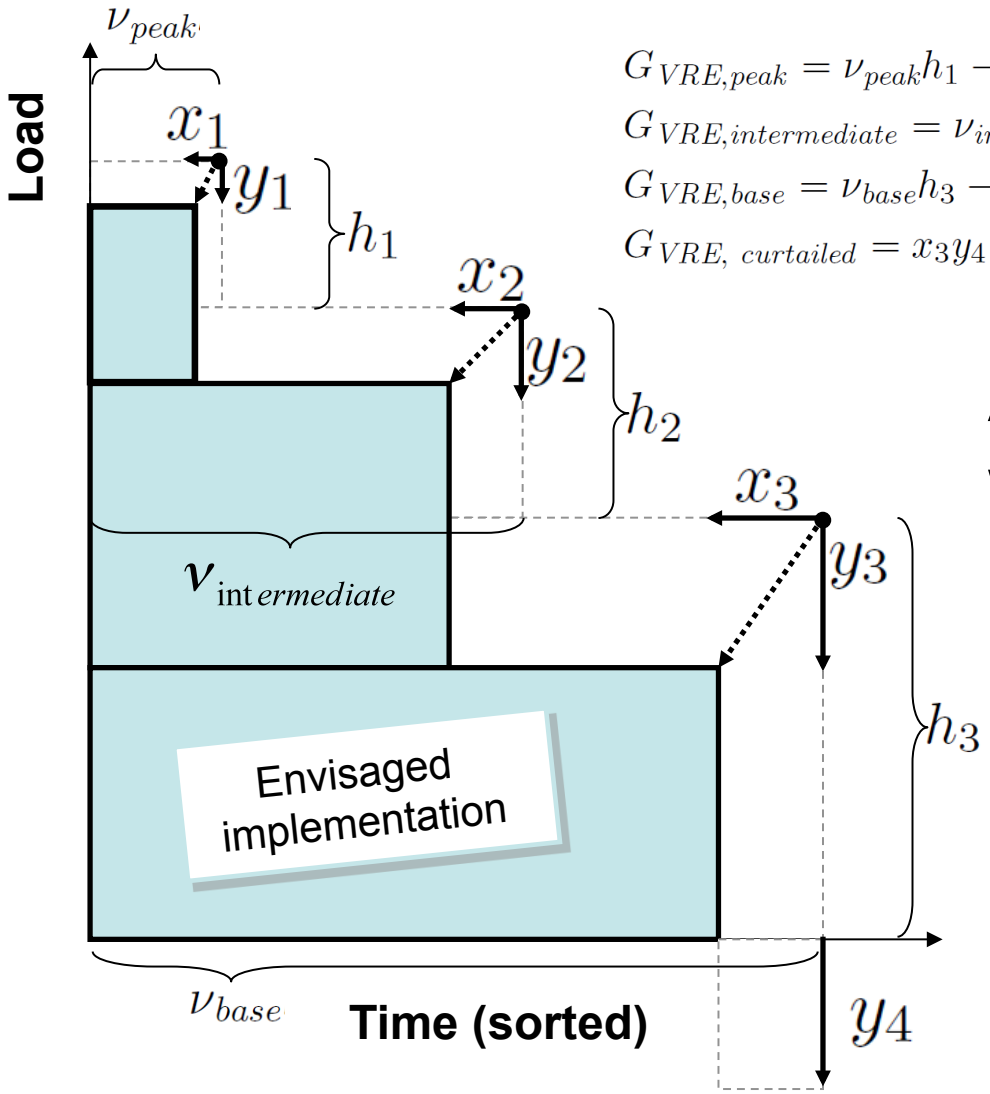
How to account for the Residual Load Duration Curve in the REMIND model?



$$G_{VRE,peak} = \nu_{peak} h_1 - (\nu_{peak} - x_1)(h_1 + y_2 - y_1)$$
$$G_{VRE,intermediate} = \nu_{intermediate} h_2 - (\nu_{intermediate} - x_2)(h_2 + y_3 - y_2)$$
$$G_{VRE,base} = \nu_{base} h_3 - (\nu_{base} - x_3)(h_3 - y_3)$$
$$G_{VRE,\ curtailed} = x_3 y_4$$

A detailed parameterization will be derived from data:

Different „directions“ depending on

- Loadtype
- Type of variable renewable energy
- Penetration level
- Renewable mix (Correlations)
- Region (Remind-R)

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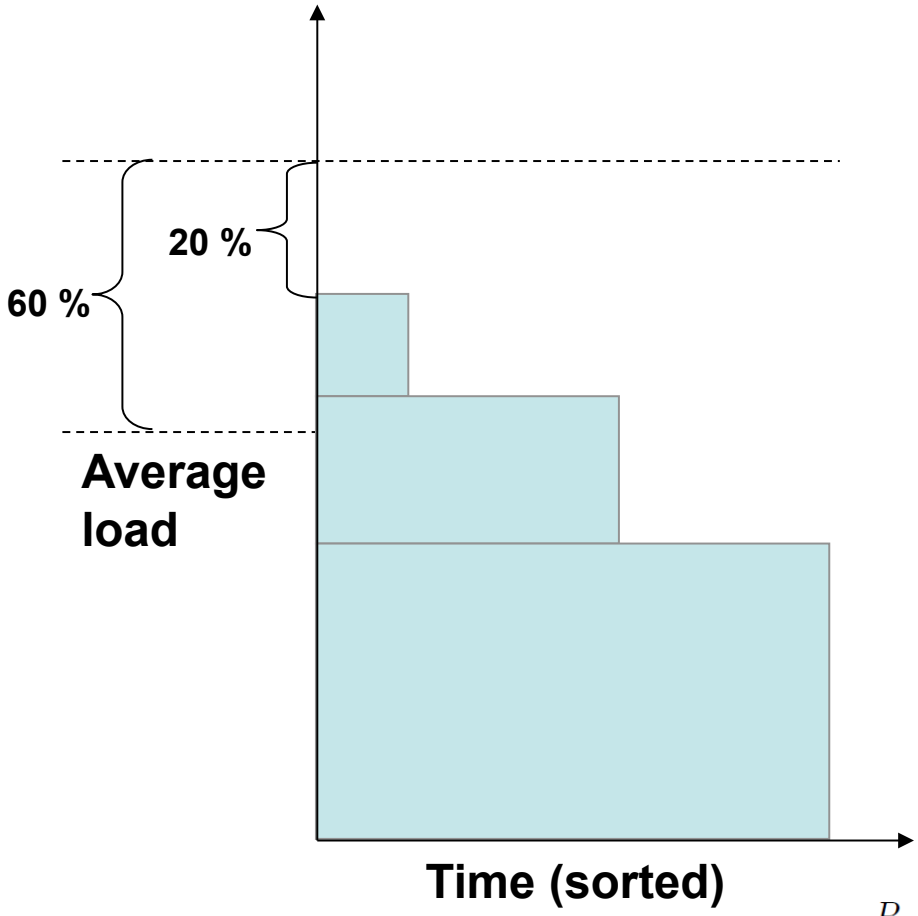
Planning reserves constraint introduced

Backup slide



Capacity reserve margin for

- transmission or plant outages
- unexpected low VRE – years

~ + 20 % extra capacity on peak (industry standard)

- Dispatchable technologies contribute their nameplate capacity
- VRE contribute a capacity value

$$1.2 \cdot P_{peak} \leq \sum_{VRE} C_{credit,\ VRE} + \sum_{Dispatchable} C_{Dispatchable}$$

P_{peak} : Height of load duration curve (peak power)

$C_{credit,\ VRE}$: Capacity credit of VRE, dependent on penetration

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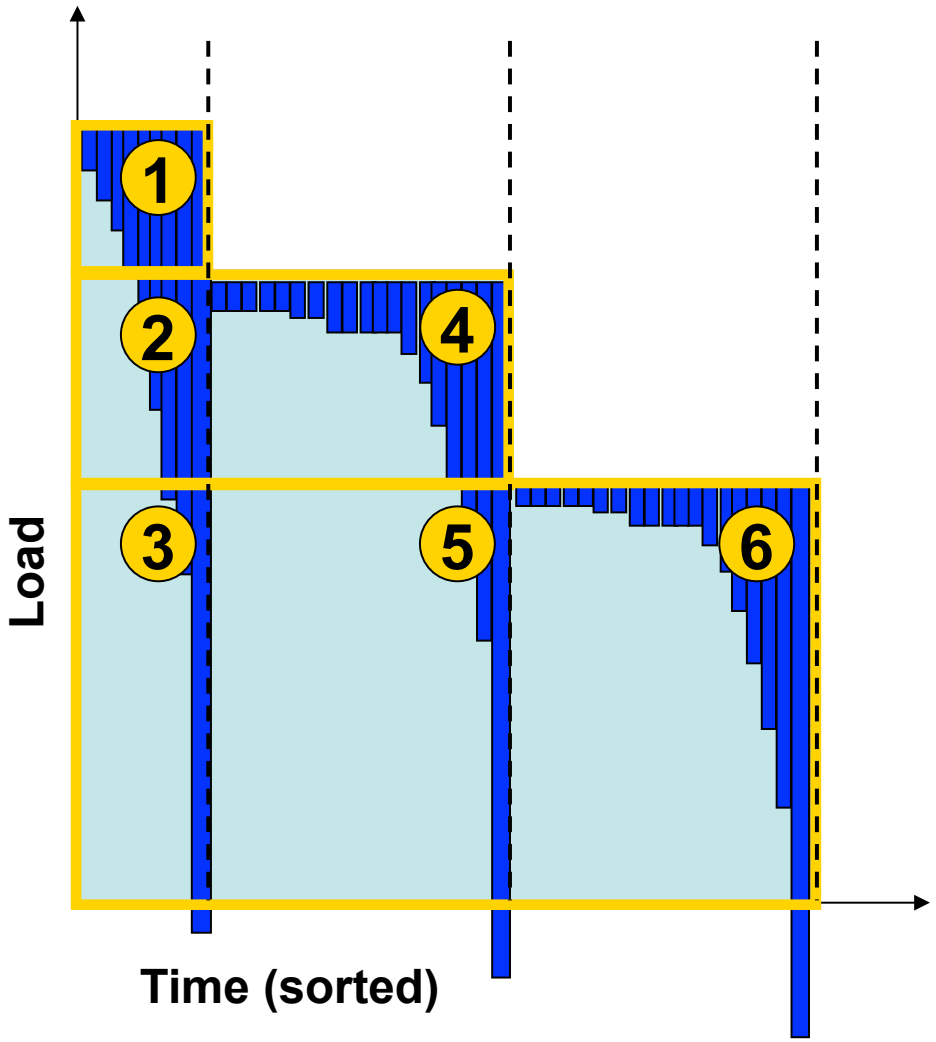
Operating reserves – How to derive the flexibility coefficients?

Backup slide



- 3 flexibility constraints:
  one for each load type
- Consider residual load duration curve for each load level
- Evaluating 6 situations

  → Deriving (dynamic) flexibility coefficients for each load type
- Curtailments are allowed

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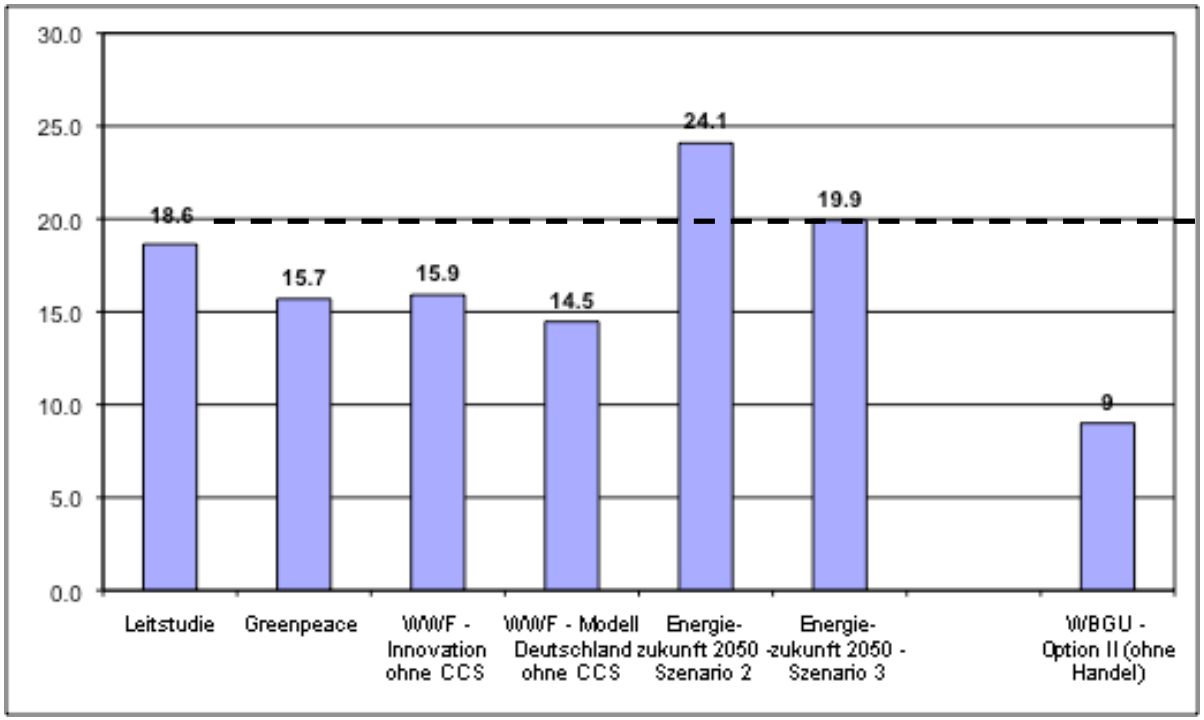
Here a budget of 20GtCO$_2$ REMIND-D is applied (2010-2050)

Backup slide



20 GtCO$_2$-Budget REMIND-D (2010-2050)

Comparison of budgets for Germany in different studies

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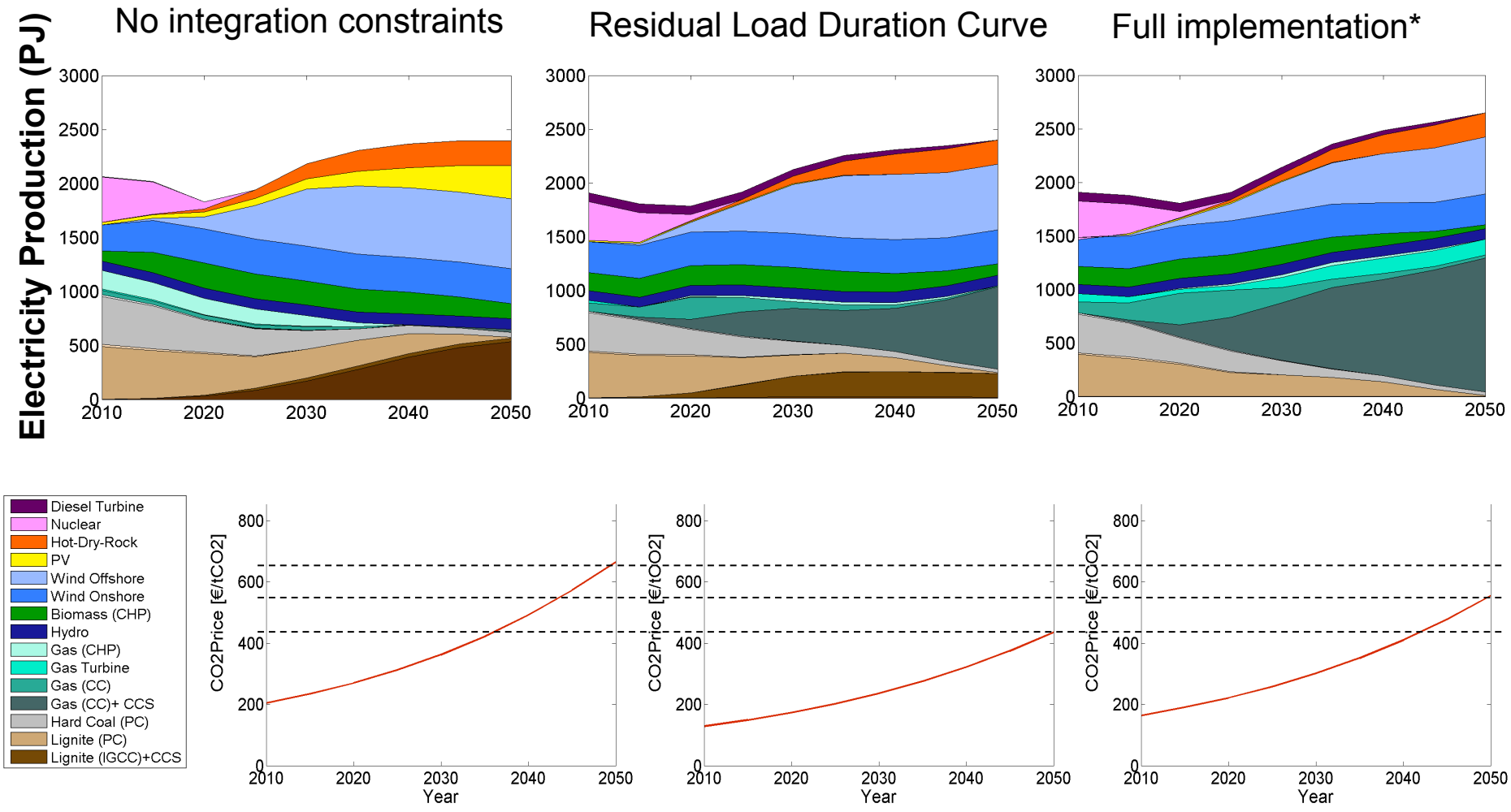
CO_2-prices



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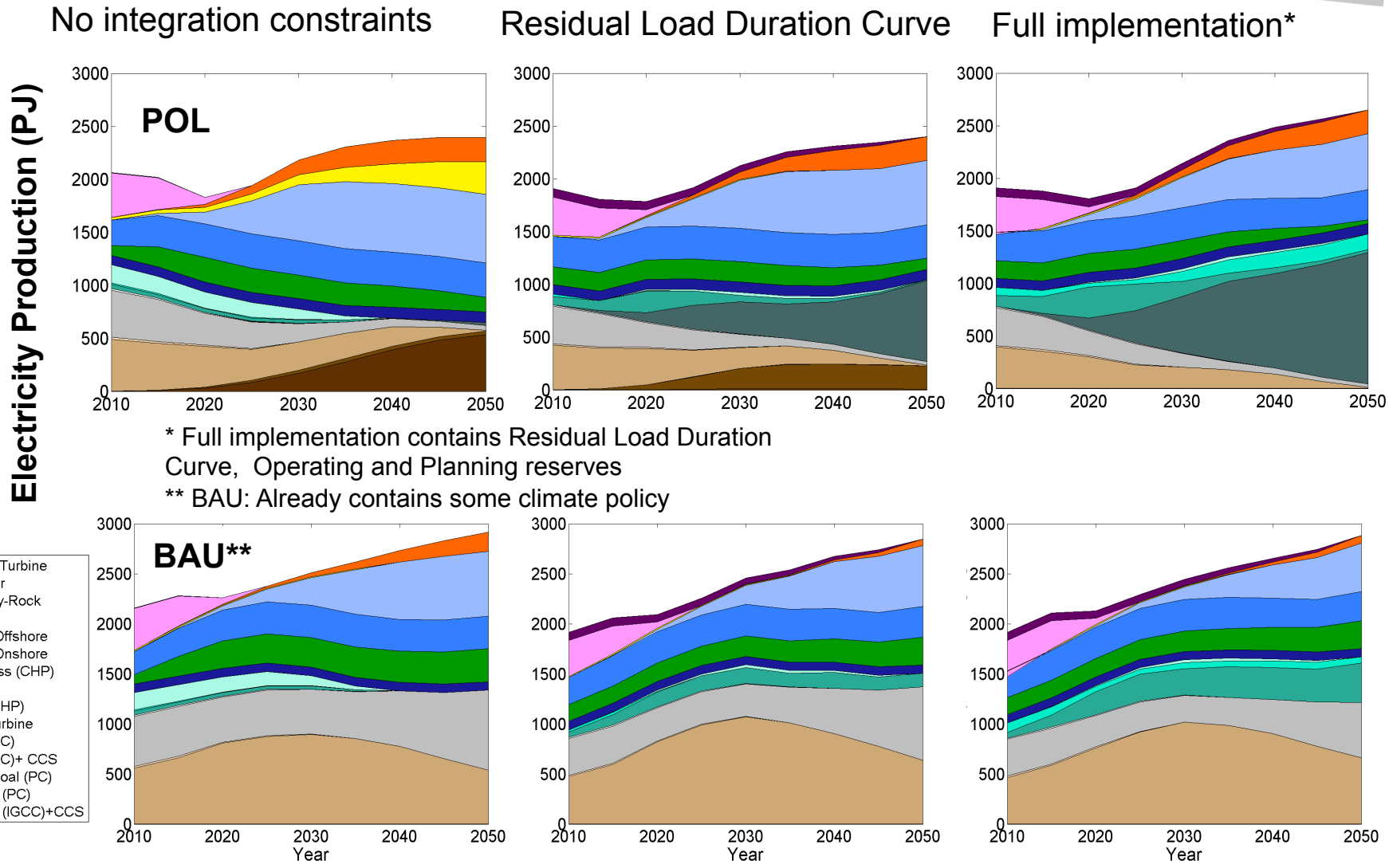
* Full implementation contains Residual Load Duration Curve, Operating and Planning reserves

Electricity mixes: POL and BAU**

Backup slide



* Full implementation contains Residual Load Duration Curve, Operating and Planning reserves

** BAU: Already contains some climate policy

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