Two-Timescale Decision-Hazard-Decision Formulation for Storage Usage Values Calculation in Energy Systems Under Uncertainty

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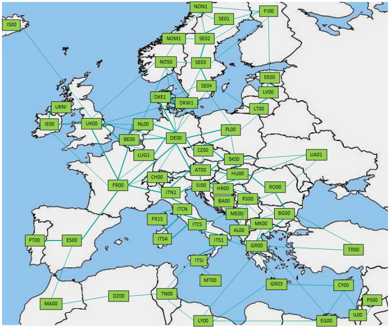
ROADEF 2024

A context of large scale prospective studies



- As the French transmission system operator, RTE conducts prospective studies on energy transition
- Penetration of renewable energy will require deploying a large number of storage facilities
- As a result, there is an increasing interest in usage value calculation for stored energy

Motivation

- The calculation of usage value for storage can be formulated as the result of stochastic multistage optimization problem with two timescales:
  - hourly controls and constraints
  - weekly planning of the decisions
- The current approach is weekly hazard-decision or weekly anticipative planning
  - delicate when units outages cannot be anticipated
- We introduce a new information structure: decision-hazard-decision

Outline

1. Prospective study problem as a stochastic multistage optimization problem in a two-timescale timeline
2. Current practice: hazard-decision
3. Exploring a new approach: decision-hazard-decision
4. Numerical results for a study case
5. Conclusions and future work

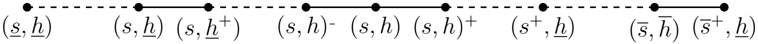
Outline

Two-timescale timeline

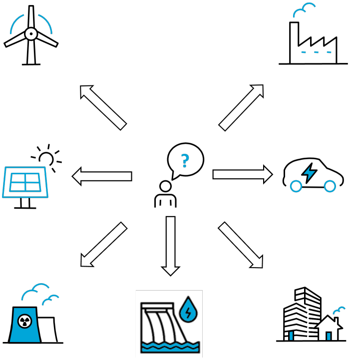
52 weeks $\mathbb{S}$ $\underline{s} \prec \cdots \prec s^{-} \prec s \prec s^{+} \prec \cdots \prec \overline{s}$

168 hours $\mathbb{H}$ $\underline{h} \prec \cdots \prec h^{-} \prec h \prec h^{+} \prec \cdots \prec \overline{h}$

- Complete timeline $\overline{\mathbb{S} \times \mathbb{H}} = \mathbb{S} \times \mathbb{H} \cup \{(\overline{s}^{+}, \underline{h})\}$



One-node system description



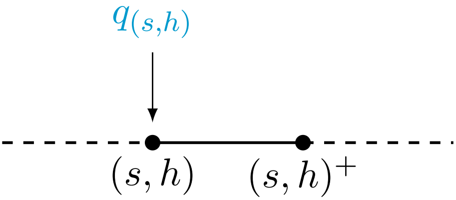
We consider a one-node system composed of:

- one storage unit (aggregated dam)
- dispatchable units
- sources of uncertainties:
  - fatal production
  - demand
  - inflows
  - dispatchable unit's availability

Variables definition in the hourly interval

Level of stock

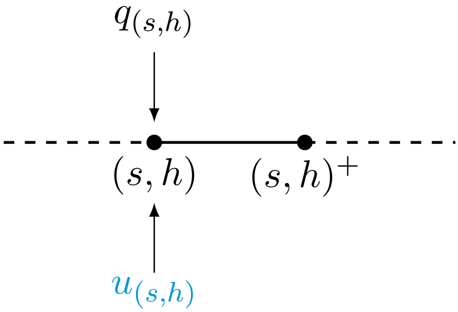
The (scalar) variable q
denotes the level of stock in the storage



Variables definition in the hourly interval

Nonanticipative or planning controls

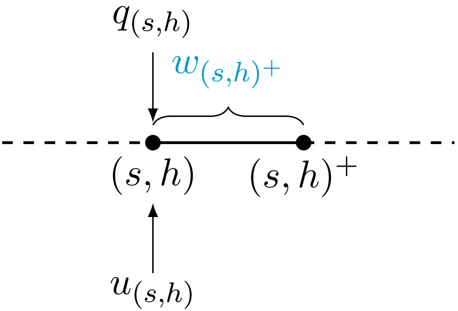
The (vector) variable u denotes the nonanticipative controls: decisions before knowing the uncertainties



Variables definition in the hourly interval

Uncertain variables

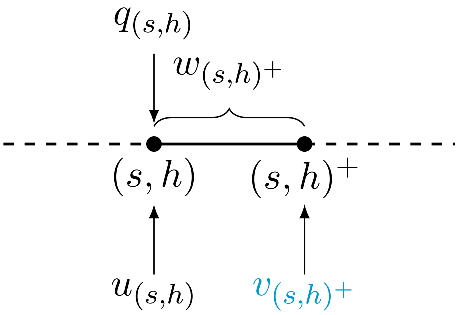
The (vector) variable w
denotes the uncertainties in the system



Variables definition in the hourly interval

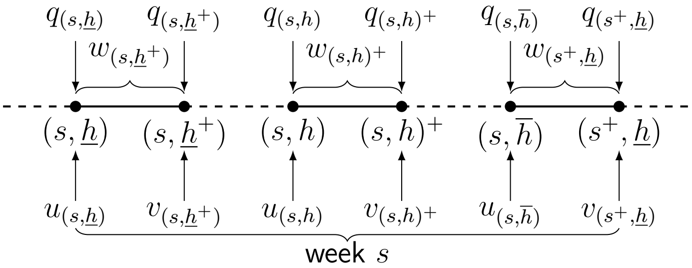
Recourse controls

The (vector) variable v denotes recourse controls:
corrective decisions made once the uncertainties are known



Compact notation for weekly variables

For the week s: 1 week = 168 hours



weekly
- planning $u_{[\![s[\![} = \big(u_{(s,\underline{h})}, u_{(s,\underline{h}^+)}, \dots, u_{(s,h)}, \dots, u_{(s,\overline{h})}\big)$
- uncertainty $w_{]\!]s]\!]} = \big(w_{(s,\underline{h}^+)}, \dots, w_{(s,h)^+}, \dots, w_{(s,\overline{h})}, w_{(s^+,\underline{h})}\big)$
- recourse $v_{]\!]s]\!]} = \big(v_{(s,\underline{h}^+)}, \dots, v_{(s,h)^+}, \dots, v_{(s,\overline{h})}, v_{(s^+,\underline{h})}\big)$

Where do we stand?

We have introduced a two-timescale timeline
and different variables indexed by its elements

- Stock's level $q_{(s,h)}$
- Planning decisions $u_{(s,h)}$
- Recourse decisions $v_{(s,h)}$
- Uncertainties $w_{(s,h)}$

and the corresponding compact weekly notation
$u_{[\![s[\![}$, $v_{]\!]s]\!]}$ and $w_{]\!]s]\!]}$

Outline

Yearly problem formulation with weekly variables

$$\inf_{\mathbf{U},\mathbf{V}} \overbrace{\mathbb{E}\left[\sum_{s\in\mathbb{S}} L_s(\mathbf{Q}_{(s,\underline{h})}, \mathbf{U}_{[\![s[\![}, \mathbf{W}_{]\!]s]\!]}, \mathbf{V}_{]\!]s]\!]}) + K(\mathbf{Q}_{(\overline{s}^+,\underline{h})})\right]}^{\text{Expected intertemporal cost}}$$

Yearly problem formulation with weekly variables

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L_s is the weekly composition of the hourly cost $L_{(s,h)}$:

$$\underbrace{L_{(s,h)}(q_{(s,h)}, u_{(s,h)}, w_{(s,h)^+}, v_{(s,h)^+})}_{\text{Instantaneous cost function}} = \underbrace{C^u(u_{(s,h)})}_{\substack{\text{cost function for}\\ \text{planning control } u}} + \underbrace{C^v(v_{(s,h)^+})}_{\substack{\text{cost function for}\\ \text{recourse control } v}}$$

$$+ \underbrace{\delta\Big(g(u_{(s,h)}, w_{(s,h)^+}, v_{(s,h)^+}) = 0\Big)}_{\text{energy balance constraint}}$$

$$+ \underbrace{\delta_{[\underline{q},\overline{q}]}\Big(f_{(s,h)}(q_{(s,h)}, u_{(s,h)}, w_{(s,h)^+}, v_{(s,h)^+})\Big)}_{\text{bounds constraint}}$$

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s.t.

$\mathbf{Q}_{(\underline{s},\underline{h})} = \mathbf{W}_{(\underline{s},\underline{h})}$ (initial condition)

Yearly problem formulation with weekly variables

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$$\mathbf{Q}_{(\underline{s},\underline{h})} = \mathbf{W}_{(\underline{s},\underline{h})}$$

$$\mathbf{Q}_{(s^+,\underline{h})} = f_s(\mathbf{Q}_{(s,\underline{h})}, \mathbf{U}_{[\![s[\![}, \mathbf{W}_{]\!]s]\!]}, \mathbf{V}_{]\!]s]\!]}) \ , \ \ \forall s \in \mathbb{S}$$

f_s is the weekly composition of the hourly dynamics $f_{(s,h)}$:

$$\mathbf{Q}_{(s,h)^+} = f_{(s,h)}(\mathbf{Q}_{(s,h)}, \mathbf{U}_{(s,h)}, \mathbf{W}_{(s,h)^+}, \mathbf{V}_{(s,h)^+})$$

Yearly problem formulation with weekly variables

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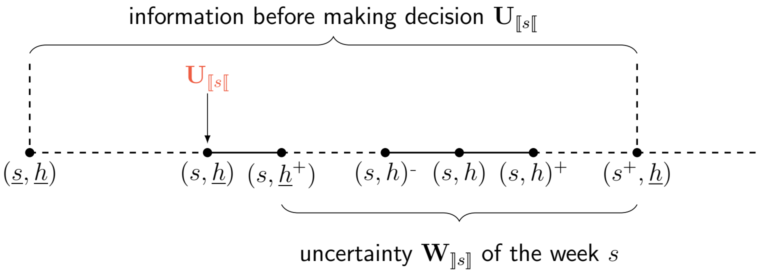
Information constraints over planning controls $\mathbf{U}_{[\![s[\![}$
and recourse controls $\mathbf{V}_{]\!]s]\!]}$

Where do we stand?

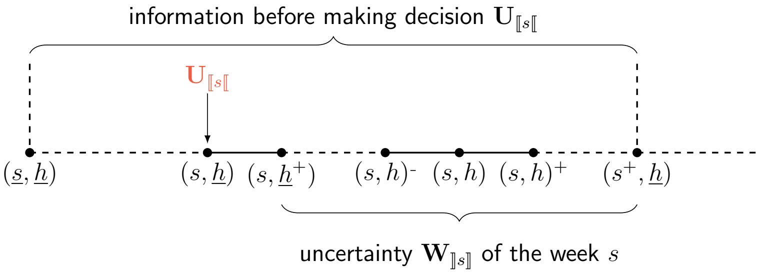
- We have described the timeline and variables
- We have formulated the problem using the (compact) weekly variables
- We have not specified the information constraints
- We now detail the current practice for information modelling

Outline

Weekly hazard-decision information structure

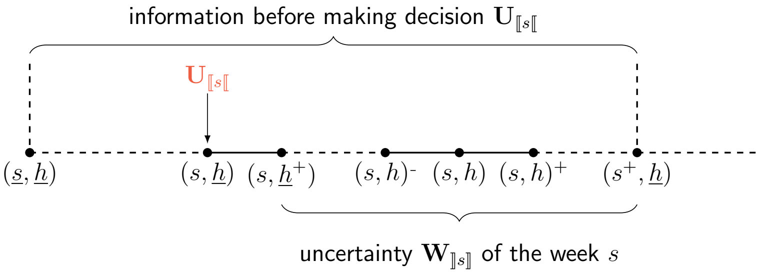


Weekly hazard-decision information structure



- The uncertainties are anticipated in weekly blocks

Weekly hazard-decision information structure



- The uncertainties are anticipated in weekly blocks
- No need for recourse controls $\mathbf{V}_{]\!]s]\!]}$

How do we value the storage?

Outline

Bellman equations for weekly hazard-decision

- Defining the weekly state $x_s = q_{(s,\underline{h})}$ (stock in the storage) we write the weekly Bellman equations

$$B^{\mathsf{HD}}_{\overline{s}^+}(x_{\overline{s}^+}) = K(x)$$

$$B^{\mathsf{HD}}_{s}(x_s) = \mathbb{E}\Bigg[\inf_{u_{[\![s[\![} \in \mathbb{U}_{[\![s[\![}} \underbrace{L_s\big(x_s, u_{[\![s[\![}, \mathbf{W}_{]\!]s]\!]}\big)}_{\text{weekly cost}} + \underbrace{B^{\mathsf{HD}}_{s^+}\big(f_s(x_s, u_{[\![s[\![}, \mathbf{W}_{]\!]s]\!]})\big)}_{\text{HD cost-to-go}}\Bigg]$$

Every week s, the Bellman function $B^{\mathsf{HD}}_{s}(x_s)$
gives the value of the storage x_s at the beginning of the week

Where do we stand?

- Bellman functions are a tool to compute usage values of storages

$$\text{storage value} = B_s(x_s)$$
$$\text{usage value} = -\frac{d}{dx_s} B_s(x_s)$$

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  - Not bad when considering uncertainties with available accurate forecast

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  - Delicate for the units outages: dispatchable units (nuclear, thermal)

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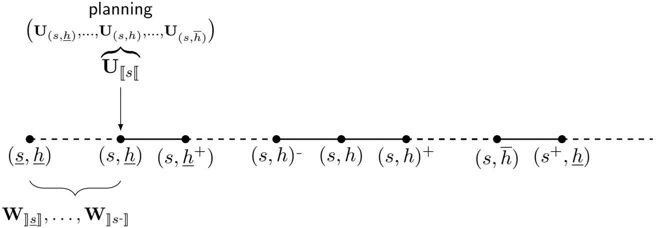
- The weekly hazard-decision structure assumes that the weekly uncertainties are known in advance
  - Not bad when considering uncertainties with available accurate forecast
  - Delicate for the units outages: dispatchable units (nuclear, thermal)
  - This is why we turn to decision-hazard-decision structure

Outline

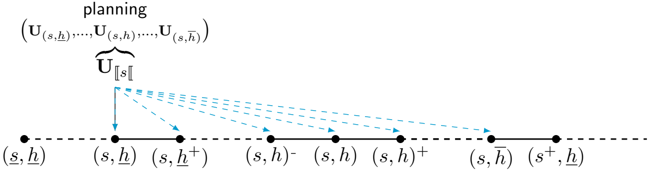
Weekly decision-hazard-decision

At the beginning of the week the vector of nonanticipative or planning decisions is made knowing only the past uncertainties



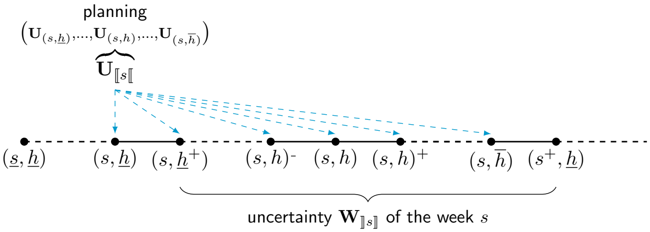
Weekly decision-hazard-decision

The 168 hours planning at the beginning of the week
has an impact on the 168 hourly balances within the week



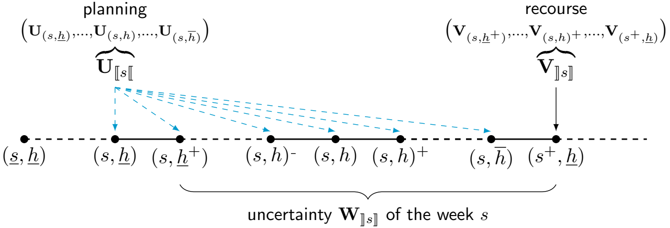
Weekly decision-hazard-decision

The weekly block of 168 uncertainties materialize



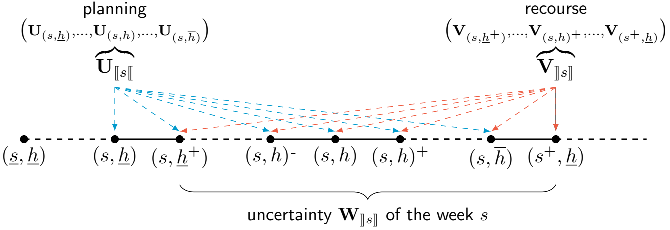
Weekly decision-hazard-decision

The vector of recourse or corrective decisions
is made knowing all the uncertainties for the week



Weekly decision-hazard-decision

The 168 hours recourse has an impact
on the hourly balances within the week



Outline

Bellman equations for weekly decision-hazard-decision

- Defining the weekly state $x_s = q_{(s,\underline{h})}$ (stock in the storage) we write the weekly Bellman equations

$$B^{\mathsf{DHD}}_{\overline{s}^+}(x_{\overline{s}^+}) = K(x_{\overline{s}^+})$$

$$B^{\mathsf{DHD}}_{s}(x_s) = \inf_{u_{[\![s[\![}} \mathbb{E}\Bigg[\inf_{v_{]\!]s]\!]}} \Big\{ \underbrace{L_s(x_s, u_{[\![s[\![}, \mathbf{W}_{]\!]s]\!]}, v_{]\!]s]\!]})}_{\text{weekly cost}} + \underbrace{B^{\mathsf{DHD}}_{s^+}\big(f_s(x_s, u_{[\![s[\![}, \mathbf{W}_{]\!]s]\!]}, v_{]\!]s]\!]})\big)}_{\text{DHD cost-to-go}} \Big\}\Bigg]$$

Every week s, the Bellman function $B^{\mathsf{DHD}}_{s}(x_s)$ gives the value of the storage x_s at the beginning of the week

Bellman equations for weekly decision-hazard-decision

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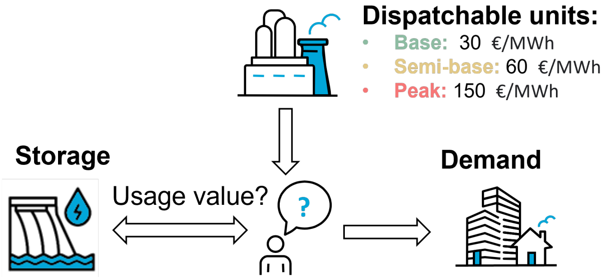
Two-stage problem for each week

Outline

Numerical results for a small study case



Physical decision variables classification for the weekly DHD model

Planning u:

Recourse v:

Physical decision variables classification for the weekly DHD model

Planning u:

$\rightarrow$ on/off base unit

Recourse v:

Physical decision variables classification for the weekly DHD model

Planning u:

- $\rightarrow$ on/off base unit
- $\rightarrow$ on/off semi-base unit

Recourse v:

Physical decision variables classification for the weekly DHD model

Planning u:

$\rightarrow$ on/off base unit

$\rightarrow$ on/off semi-base unit

Recourse v:

$\rightarrow$ on/off peak unit

Physical decision variables classification for the weekly DHD model

Planning u:

- → on/off base unit
- → on/off semi-base unit

Recourse v:

- → on/off peak unit
- → power modulation base unit

Physical decision variables classification for the weekly DHD model

Planning u:

- $\rightarrow$ on/off base unit
- $\rightarrow$ on/off semi-base unit

Recourse v:

- $\rightarrow$ on/off peak unit
- $\rightarrow$ power modulation base unit
- $\rightarrow$ power modulation semi-base unit

Physical decision variables classification for the weekly DHD model

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- $\rightarrow$ on/off base unit
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Recourse v:

- $\rightarrow$ on/off peak unit
- $\rightarrow$ power modulation base unit
- $\rightarrow$ power modulation semi-base unit
- $\rightarrow$ power modulation peak unit

Physical decision variables classification for the weekly DHD model

Planning u:

- $\rightarrow$ on/off base unit
- $\rightarrow$ on/off semi-base unit

Recourse v:

- $\rightarrow$ on/off peak unit
- $\rightarrow$ power modulation base unit
- $\rightarrow$ power modulation semi-base unit
- $\rightarrow$ power modulation peak unit
- $\rightarrow$ storage charge and discharge

Bellman functions and usage values

We compute the Bellman functions for all weeks s in the year and x in a discretization of the state space

$$B_s^{\mathsf{HD}}(x) \qquad\qquad B_s^{\mathsf{DHD}}(x)$$

Bellman functions and usage values

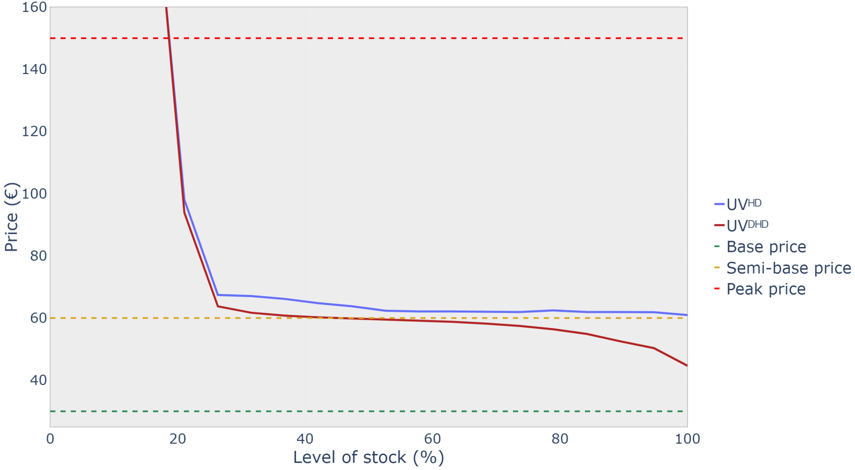
We compute the Bellman functions for all weeks s in the year and x in a discretization of the state space

$$B_s^{\mathsf{HD}}(x) \qquad\qquad B_s^{\mathsf{DHD}}(x)$$

And the corresponding usage values

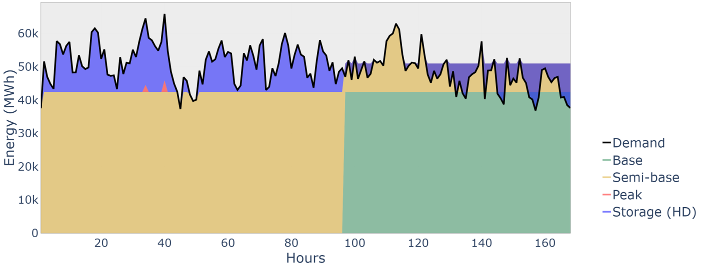
$$\mathsf{UV}^{\mathsf{HD}} = -\frac{d}{dx}B_s^{\mathsf{HD}}(x) \qquad \mathsf{UV}^{\mathsf{DHD}} = -\frac{d}{dx}B_s^{\mathsf{DHD}}(x)$$

Usage value comparison

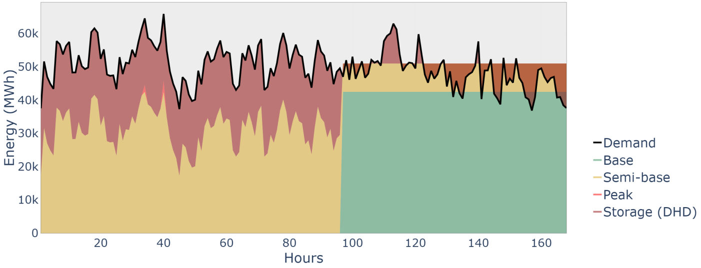


Weekly allocation comparison

Hazard-decision



Decision-hazard-decision



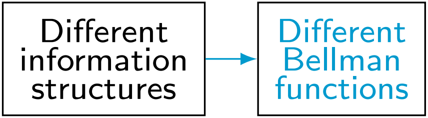
Difference in the storage level trajectories

Outline

From the study case we conclude that...

Different information structures

From the study case we conclude that...



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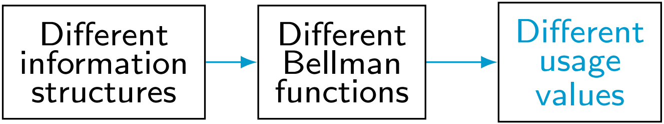

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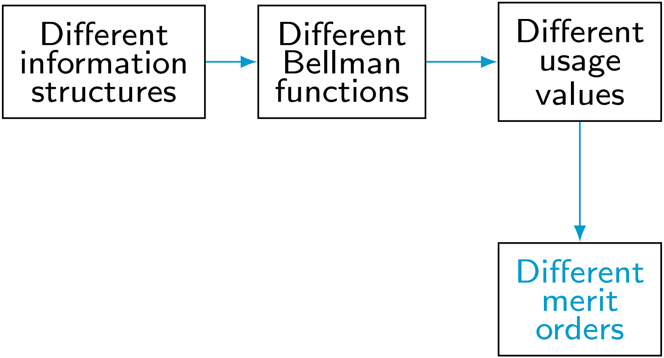
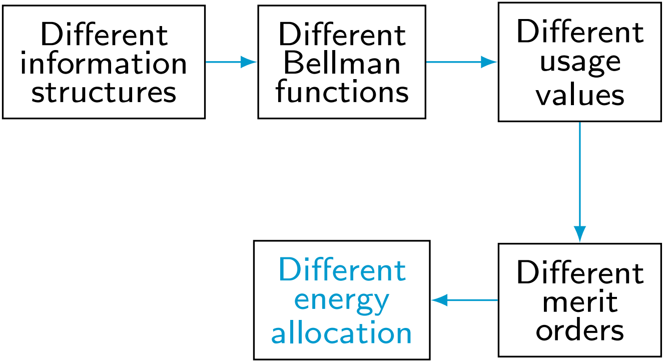
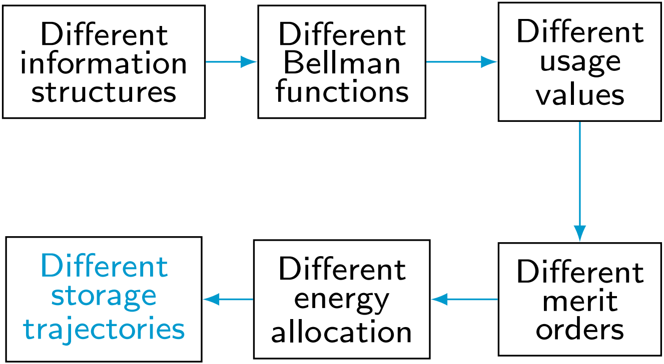


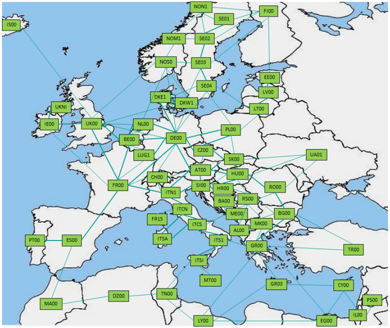
From the study case we conclude that...



From the study case we conclude that...



Future work



- Currently working on how to compute solutions of DHD Bellman equations for a real scale problem
- Extend to multiple nodes with multiple storages
- Spatial decomposition techniques mixed with stochastic dynamic programming

Thank you, questions?