DSM modeling in oemof.solph

Introducing the custom component SinkDSM

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Project context

- Research project WindNODE
- Building a regional ESM for Anhalt-Bitterfeld-Wittenberg
- Intended analysis: potential of flexibility options to foster regional energy supply
- Demand-Side Management in households is one option

Code (under development): https://github.com/windnode/WindNODE_ABW
A minimal testing energy system

Assuming we have a household including

Household busbar
Assuming we have a household including
  - Demand

Household busbar
A minimal testing energy system

Assuming we have a household including
- Demand
- PV

Household busbar
A minimal testing energy system

Assuming we have a household including
- Demand
- PV
- Grid connection

Household busbar
A minimal testing energy system

Assuming we have a household including
- Demand
- PV
- Grid connection
- Demand-side management unit

Household busbar
# Create some data

```python
pv_day = [(-(1 / 6 * x ** 2) + 6) / 6 for x in range(-6, 7)]
pv_ts = [0] * 6 + pv_day + [0] * 6
```

```python
data_dict = {
    "demand_el": [3] * len(pv_ts),
    "pv": pv_ts,
    "Cap_up": [0.5] * len(pv_ts),
    "Cap_do": [0.5] * len(pv_ts)
}
```

```python
data = pd.DataFrame.from_dict(data_dict)
```

# Do timestamp stuff

```python
datetimeindex = pd.date_range(start='1/1/2013', periods=len(data.index),
                              freq='H')
data['timestamp'] = datetimeindex
```

```python
data.set_index('timestamp', inplace=True)
```
Surrounding minimal energy system

```python
es = solph.EnergySystem(timeindex=datetimeindex)
Node.registry = es

b_elec = solph.Bus(label='Electricity bus')

grid = solph.Source(
    label='Grid',
    outputs={b_elec: solph.Flow(nominal_value=10000, variable_costs=50)})

pv = solph.Source(
    label='pv',
    outputs={b_elec: solph.Flow(actual_value=data['pv'], fixed=True, nominal_value=3.5)})
```
SinkDSM component

# Create DSM Sink

demand_dsm = solph.custom.SinkDSM(label='DSM',
                                   inputs={b_elec: solph.Flow()},
                                   capacity_up=data['Cap_up'],
                                   capacity_down=data['Cap_do'],
                                   delay_time=6,
                                   demand=data['demand_el'],
                                   method="delay",
                                   cost_dsm_down=5)
How to model DSM?

On the representation of demand-side management in power system models

Alexander Zerrahn, Wolf-Peter Schill

Highlights

- We suggest improving the DSM model used by Göransson et al. (2014).
- Including an additional constraint resolves the problem of undue DSM recovery.
- We further develop an alternative DSM model which is both concise and linear.
- Our model does not impose a specific temporal structure on load shifts.
- Our formulation could readily be included in a wide range of energy models.

Abstract
DSM formulation 1: Zerrahn & Schill (delay)

\[
\dot{E}_t = \text{demand}_t + DSM_{t}^{up} - \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T}
\]  

(1)
DSM formulation 1: Zerrahn & Schill (delay)

\[
\dot{E}_t = \text{demand}_t + DSM_{t}^{up} - \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \tag{1}
\]

\[
DSM_{t}^{up} = \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \tag{2}
\]
DSM formulation 1: Zerrahn & Schill (delay)

\[
\dot{E}_t = demand_t + DSM_{t}^{up} - \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \quad (1)
\]

\[
DSM_{t}^{up} = \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \quad (2)
\]

\[
DSM_{t}^{up} \leq E_{t}^{up} \quad \forall t \in \mathbb{T} \quad (3)
\]
DSM formulation 1: Zerrahn & Schill (delay)

\[ \dot{E}_t = \text{demand}_t + DSM_{t}^{up} - \sum_{tt = t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \quad (1) \]

\[ DSM_{t}^{up} = \sum_{tt = t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \quad (2) \]

\[ DSM_{t}^{up} \leq E_{t}^{up} \quad \forall t \in \mathbb{T} \quad (3) \]

\[ \sum_{t = tt-L}^{tt+L} DSM_{t,tt}^{do} \leq E_{tt}^{do} \quad \forall tt \in \mathbb{T} \quad (4) \]
DSM formulation 1: Zerrahn & Schill (delay)

\[ \dot{E}_t = \text{demand}_t + DSM_{t}^{up} - \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \tag{1} \]

\[ DSM_{t}^{up} = \sum_{tt=t-L}^{t+L} DSM_{t,tt}^{do} \quad \forall t \in \mathbb{T} \tag{2} \]

\[ DSM_{t}^{up} \leq E_{t}^{up} \quad \forall t \in \mathbb{T} \tag{3} \]

\[ \sum_{t=tt-L}^{tt+L} DSM_{t,tt}^{do} \leq E_{tt}^{do} \quad \forall tt \in \mathbb{T} \tag{4} \]

\[ DSM_{t}^{up} + \sum_{tt=t-L}^{tt+L} DSM_{t,tt}^{do} \leq \max\{E_{tt}^{up}, E_{tt}^{do}\} \quad \forall tt \in \mathbb{T} \tag{5} \]
Basic testing data
How it works

Delay time: 3

What’s happening

▶ Interrupted wind generation in hour 4 set 100 MWh on hold
▶ Doubled wind generation in hour 7 compensates for demand that is set on hold
▶ Doubled wind generation around afternoon on the second day goes to excess
Shifting energy exceeding the delay time (basic)

**Delay time:** 1

**What’s happening**

- DSM allows to shift energy from first day morning to second day afternoon. How is that possible?
- Zerrahn et al.’s (2015) constraints allow to trigger $DSM_{up}$ and $DSM_{do}$ at the same time
- $DSM_{up}$ and $DSM_{do}$ are constrained to the tighter bound (Eq. (5))
Limited by DSM events in between (50 %)

Delay time: 1

Intermediate DSM trigger:
50 % of $DSM_{up}$

What's happening
- DSM activity in the morning of the first day: 50 MWh
- DSM shift that exceeds the delay time is limited: 50 MWh → 25 MWh
Effect of delay time

Delay time: 1

What’s happening

- DSM shift exceeding the delay of 50 MWh
Effect of delay time

Delay time: 2

What’s happening

▶ Longer delay times allow for more DSM shifts exceeding the delay time
Effect of delay time

Delay time: 3

What's happening ➤ ...and more
Effect of delay time

Delay time: 6

What’s happening
▶ and even more
Effect of delay time

Delay time: 6

What’s happening and even more

But...

the modeler interprets his/her results!
DSM modeling for households

Available data: technical DSM potential for groups of households
DSM potential

![Chart showing DSM potential with time-of-use pricing categories.]

- Max Stundenwerte leicht Flex Minus
- Max Stundenwerte leicht Flex Plus
- zugeh Max Flex Minus Werte
- zugeh Max Flex Plus Werte

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DSM formulation 2: Interval

The dataset for DSM potential does not allow to shift energy across days!

\[ \dot{E}_t = \text{demand}_t + DSM_{up\ t} - DSM_{down\ t} \quad \forall t \in \mathbb{T} \]  

\[ DSM_{up\ t} \leq E_{up\ t} \quad \forall t \in \mathbb{T} \]  

\[ DSM_{down\ t} \leq E_{down\ t} \quad \forall t \in \mathbb{T} \]  

\[ t_s + \tau \sum_{t=t_s}^{t=t_s+\tau} DSM_{up\ t} = t_s + \tau \sum_{t=t_s}^{t=t_s+\tau} DSM_{down\ t} \quad \forall t \in \mathbb{T} \]  

Using \( \tau = 1 \) sets the window for DSM activity to exactly one day.
DSM formulation 2: Interval

The dataset for DSM potential does not allow to shift energy across days!

\[ \dot{E}_t = demand_t + DSM_{t}^{up} - DSM_{t}^{do} \quad \forall t \in \mathbb{T} \quad (6) \]
DSM formulation 2: Interval

The dataset for DSM potential does not allow to shift energy across days!

\[ \dot{E}_t = demand_t + DSM^\text{up}_t - DSM^\text{do}_t \quad \forall t \in \mathbb{T} \]  

(6)

\[ DSM^\text{up}_t \leq E^\text{up}_t \quad \forall t \in \mathbb{T} \]  

(7)
DSM formulation 2: Interval

The dataset for DSM potential does not allow to shift energy across days!

\[ \dot{E}_t = \text{demand}_t + DSM_{t}^{up} - DSM_{t}^{do} \quad \forall t \in \mathbb{T} \]  
\[ DSM_{t}^{up} \leq E_{t}^{up} \quad \forall t \in \mathbb{T} \]  
\[ DSM_{t}^{do} \leq E_{t}^{do} \quad \forall t \in \mathbb{T} \]  

\( \sum_{t}^{t+s+\tau} DSM_{t}^{up} = \sum_{t}^{t+s+\tau} DSM_{t}^{do} \quad \forall t, s, \tau \in \mathbb{T} \)
The dataset for DSM potential does not allow to shift energy across days!

\[
\dot{E}_t = \text{demand}_t + DSM_{t}^{up} - DSM_{t}^{do} \quad \forall t \in \mathbb{T} \tag{6}
\]

\[
DSM_{t}^{up} \leq E_{t}^{up} \quad \forall t \in \mathbb{T} \tag{7}
\]

\[
DSM_{t}^{do} \leq E_{t}^{do} \quad \forall t \in \mathbb{T} \tag{8}
\]

\[
\sum_{t=t_s}^{t_s+\tau} DSM_{t}^{up} = \sum_{t=t_s}^{t_s+\tau} DSM_{t}^{do} \quad \forall t_s \in \{k \in \mathbb{T} | k \mod \tau = 0\} \tag{9}
\]
DSM formulation 2: Interval

The dataset for DSM potential does not allow to shift energy across days!

\[ \dot{E}_t = demand_t + DSM_{t}^{up} - DSM_{t}^{do} \quad \forall t \in \mathbb{T} \] \hspace{1cm} (6)

\[ DSM_{t}^{up} \leq E_{t}^{up} \quad \forall t \in \mathbb{T} \] \hspace{1cm} (7)

\[ DSM_{t}^{do} \leq E_{t}^{do} \quad \forall t \in \mathbb{T} \] \hspace{1cm} (8)

\[ \sum_{t=t_s}^{t_s+\tau} DSM_{t}^{up} = \sum_{t=t_s}^{t_s+\tau} DSM_{t}^{do} \quad \forall t_s \in \{k \in \mathbb{T} | k \mod \tau = 0\} \] \hspace{1cm} (9)

Using \( \tau = 1 \) sets the window for DSM activity to exactly one day.
Comparing both formulations – delay method
Comparing both formulations – interval method

1HH_3Personen

10HH

50HH

demand_el
demand_dsm
cap_up
cap_do
wind
pv
coal1

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DSM energy on hold

DSM on hold

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## Comparison by numbers

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<thead>
<tr>
<th></th>
<th>demand_el</th>
<th>dsm_tot</th>
<th>excess</th>
<th>cap_up</th>
<th>cap_do</th>
<th>wind</th>
<th>pv</th>
<th>coal</th>
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</thead>
<tbody>
<tr>
<td>1 HH 3 P. [delay]</td>
<td>91.0</td>
<td>18.0</td>
<td>43.0</td>
<td>109.0</td>
<td>34.0</td>
<td>96.0</td>
<td>15.0</td>
<td>23.0</td>
</tr>
<tr>
<td>10 HH</td>
<td>92.0</td>
<td>14.0</td>
<td>42.0</td>
<td>59.0</td>
<td>27.0</td>
<td>96.0</td>
<td>15.0</td>
<td>22.0</td>
</tr>
<tr>
<td>50 HH [delay]</td>
<td>89.0</td>
<td>13.0</td>
<td>43.0</td>
<td>57.0</td>
<td>27.0</td>
<td>96.0</td>
<td>15.0</td>
<td>21.0</td>
</tr>
<tr>
<td>100 HH [delay]</td>
<td>88.0</td>
<td>13.0</td>
<td>44.0</td>
<td>53.0</td>
<td>26.0</td>
<td>96.0</td>
<td>15.0</td>
<td>21.0</td>
</tr>
<tr>
<td>1 HH 3 P. [interval]</td>
<td>91.0</td>
<td>18.0</td>
<td>44.0</td>
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<tr>
<td>10 HH [interval]</td>
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<tr>
<td>50 HH [interval]</td>
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<td>96.0</td>
<td>15.0</td>
<td>22.0</td>
</tr>
</tbody>
</table>
1. Who plans to model DSM with oemof.solph in the near future?
2. Further development of SinkDSM
   - Move to `solph.Components` by v0.4.0?
   - Responsibility for SinkDSM?
   - Roadmap
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