Updated version as of 2023-04-29

Multi-period modeling in oemof.solph

An Overview

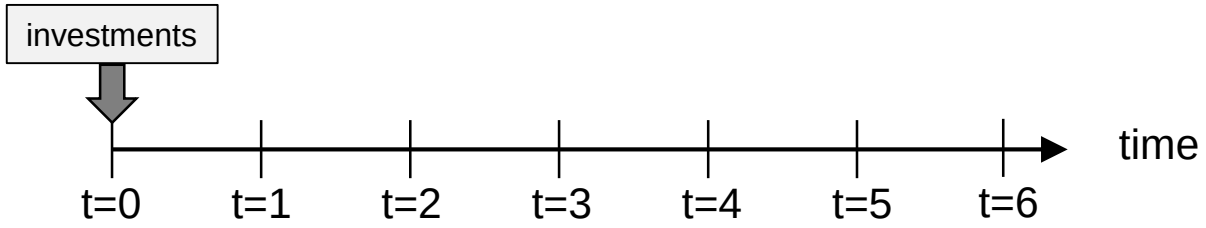
–

Motivation | Usage Example | Implementation

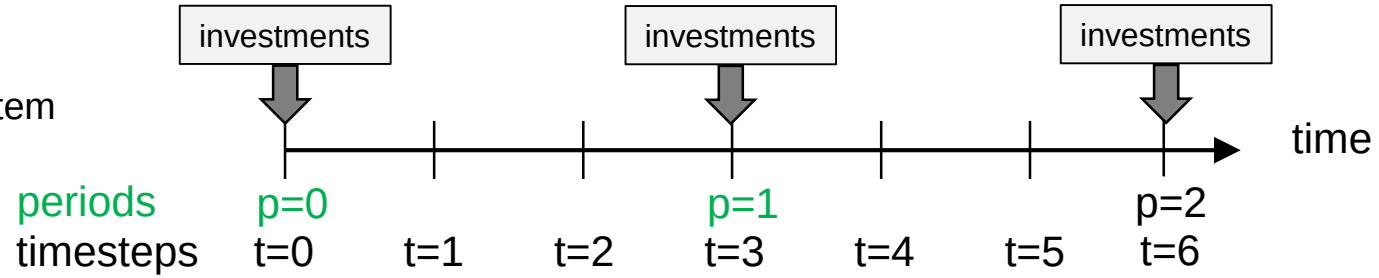
Motivation

Depict long-term developments taking into account unit lifetimes

- **Status quo** in oemof.solph
  - Only one timestep where investments may occur → t=0, i.e. the begin of the optimization
  - Investments are accounted for by their annuity
  - Timesteps are a one-dimensional set
  - Classical use case: Dimensioning of a system; short-term view (e.g. one typical year)



- Idea of **a multi-period optimization** model
  - Depict different periods in addition to different timesteps → there are two time-related indices
  - Investments may occur in every period
  - Lifetime tracking
  - Classical use case: long-term planning of a system



Example usage

Define `periods` attribute of EnergySystem

Periods now need to be defined explicitly
and passed to the EnergySystem instance as an attribute.

```python
import pandas as pd
import oemof.solph as solph

my_index = pd.date_range('1/1/2013', periods=17520, freq='H')
periods = {
    0: pd.date_range('1/1/2013', periods=8760, freq='H'),
    1: pd.date_range('1/1/2013', periods=8760, freq='H'),
}
my_energysystem = solph.EnergySystem(timeindex=my_index, periods=periods)
```

Example usage

No need for changes to your „dispatch-related“ system

```
hydrogen_bus = solph.buses.Bus(label="hydrogen")
coal_bus = solph.buses.Bus(label="coal")
electricity_bus = solph.buses.Bus(label="electricity")

hydrogen_source = solph.components.Source(
    label="green_hydrogen",
    outputs={
        hydrogen_bus: solph.flows.Flow(
            variable_costs=[25] * 8760 + [30] * 8760
        )
    },
)

coal_source = solph.components.Source(
    label="hardcoal",
    outputs={
        coal_bus: solph.flows.Flow(variable_costs=[20] * 8760 + [24] * 8760)
    },
)

electrical_sink = solph.components.Sink(
    label="electricity_demand",
    inputs={
        electricity_bus: solph.flows.Flow(
            nominal_value=1000, fix=[0.8] * len(my_index)
        )
    },
)
```

Variable costs defined in TIMESTEPS.

No changes to your system for units that is not invested into.

Example usage

Investments have new attributes

```
hydrogen_power_plant = solph.components.Transformer(
    label="hydrogen_pp",
    inputs={hydrogen_bus: solph.flows.Flow()},
    outputs={
        electricity_bus: solph.flows.Flow(
            investment=solph.Investment(
                maximum=1000,
                ep_costs=1e6,
                lifetime=30,
                interest_rate=0.06,
                fixed_costs=100,
            ),
            variable_costs=3,
        )
    },
    conversion_factors={electricity_bus: 0.6},
)
```

ep_costs used as specific investment expenses;
nominal values on a period / annual basis; real values possible if model `discount_rate` is set to 0.

`lifetime` and `age` (optional; defaults to 0) for lifetime tracking and decommissioning

Implementation – Main changes

Overview on the main changes

- Add `periods` to `EnergySystem` class.
- Add `discount_rate` attribute to `Model` (default: 0.02).
- Create new timesets:
  - `PERIODS`: used for investment variables
  - `TIMEINDEX`: tuple of (period, timestep)
- Index `flow` variable in `TIMEINDEX`. Adjust every constraint that includes a flow;
  but do not change indexing of variables indexed in `TIMESTEPS`.
- Add additional attributes to `_options.Investment`, `GenericStorage` and `SinkDSM`:
  `lifetime`, `age`, `interest_rate`, `fixed_costs`.
- Add variables `old`, `old_end` and `old_exo` in investment blocks for lifetime tracking.
- Add adjusted objective value terms for multi-period model including discounting and annuities for investment.
- Adjust / restructure processing to properly retrieve results.

Implementation – oemof.solph._energy_system.py

constructor of EnergySystem – `periods` attribute

```
if periods is not None:
    msg = (
        "CAUTION! You specified the 'periods' attribute for your "
        "energy system.\n This will lead to creating "
        "a multi-period optimization modeling which can be "
        "used e.g. for long-term investment modeling.\n"
        "Please be aware that the feature is experimental as of "
        "now. If you find anything suspicious or any bugs, "
        "please report them."
    )
    warnings.warn(msg, debugging.SuspiciousUsageWarning)
self.periods = _add_periods(periods)
self._extract_periods_years()
```

function `_add_periods`

```
def _add_periods(periods):
    """Returns periods to be added to the energy system..."""
    if periods is not None:
        for k in periods.keys():
            if not isinstance(k, int):
                raise ValueError("Period keys must be of type int.")

    return periods
```

method `EnergySystem._extract_periods_years`

```
def _extract_periods_years(self):
    """Map simulation years to the respective period based on time indices..."""
    periods_years = {0: 0}
    if self.periods is not None:
        start_year = self.periods[0].min().year
        for k, v in self.periods.items():
            if k >= 1:
                periods_years[k] = v.min().year - start_year

        self.periods_years = periods_years
```

Implementation – oemof.solph._models.py

constructor of Model – `discount_rate` attribute

```python
def __init__(self, energysystem, discount_rate=None, **kwargs):
    if discount_rate is not None:
        self.discount_rate = discount_rate
    elif energysystem.periods is not None:
        self.discount_rate = 0.02
        msg = (
            f"By default, a discount_rate of {self.discount_rate} "
            f"is used for a multi-period model. "
            f"If you want to use another value, "
            f"you have to specify the `discount_rate` attribute."
        )
        warnings.warn(msg, debugging.SuspiciousUsageWarning)
    super().__init__(energysystem, **kwargs)
```

Implementation – oemof.solph._models.py

method `Model._add_parent_block_sets`

```python
if self.es.periods is None:
    self.TIMEINDEX = po.Set(
        initialize=list(
            zip(
                [0] * len(self.es.timeincrement),
                range(len(self.es.timeincrement)),
            )
        ),
        ordered=True,
    )
    self.PERIODS = po.Set(initialize=[0])
else:
    nested_list = [
        [k] * len(self.es.periods[k]) for k in self.es.periods.keys()
    ]
    flattened_list = [
        item for sublist in nested_list for item in sublist
    ]
    self.TIMEINDEX = po.Set(
        initialize=list(
            zip(flattened_list, range(len(self.es.timeincrement)))
        ),
        ordered=True,
    )
    self.PERIODS = po.Set(
        initialize=sorted(list(set(self.es.periods.keys())))
    )
```

```python
# (Re-)Map timesteps to periods
timesteps_in_period = {p: [] for p in self.PERIODS}
for p, t in self.TIMEINDEX:
    timesteps_in_period[p].append(t)
self.TIMESTEPS_IN_PERIOD = timesteps_in_period
```

Implementation – oemof.solph._models.py

method Model._add_parent_block_variables

```
self.flow = po.Var(self.FLOWS, self.TIMEINDEX, within=po.Reals)

for o, i in self.FLOWS:
    if self.flows[o, i].nominal_value is not None:
        if self.flows[o, i].fix[self.TIMESTEPS.at(1)] is not None:
            for p, t in self.TIMEINDEX:
                self.flow[o, i, p, t].value = (
                    self.flows[o, i].fix[t]
                    * self.flows[o, i].nominal_value
                )
                self.flow[o, i, p, t].fix()
```

Implementation – oemof.solph._options.Investment

- **overall_maximum** (float, $P_{overall,max}$ or $E_{overall,max}$) – Overall maximum capacity investment, i.e. the amount of capacity that can be totally installed at maximum in any period (taking into account decommissionings); only applicable for multi-period models
- **overall_minimum** (float $P_{overall,min}$ or $E_{overall,min}$) – Overall minimum capacity investment that needs to be installed in the last period of the optimization (taking into account decommissionings); only applicable for multi-period models
- **lifetime** (int, l) – Units lifetime, given in years; only applicable for multi-period models
- **age** (int, a) – Units start age, given in years at the beginning of the simulation; only applicable for multi-period models
- **interest_rate** (float, ir) – Interest rate for calculating annuities when investing in a particular unit; only applicable for multi-period models. If nothing else is specified, the interest rate is the same as the model discount rate of the multi-period model.
- **fixed_costs** (float or list of float, $c_{fixed}(p)$) – Fixed costs in each period (given in nominal terms); only applicable for multi-period models

Implementation – oemof.solph.flows._invest_flow

```python
self.invest = Var(
    self.INVESTFLOWS,
    m.PERIODS,
    within=NonNegativeReals,
    bounds=_investvar_bound_rule,
)

# Total capacity
self.total = Var(self.INVESTFLOWS, m.PERIODS, within=NonNegativeReals)

if m.es.multi_period:
    self.old = Var(
        self.INVESTFLOWS, m.PERIODS, within=NonNegativeReals
    )

    # Old endogenous capacity to be decommissioned (due to lifetime)
    self.old_end = Var(
        self.INVESTFLOWS, m.PERIODS, within=NonNegativeReals
    )

    # Old exogenous capacity to be decommissioned (due to lifetime)
    self.old_exo = Var(
        self.INVESTFLOWS, m.PERIODS, within=NonNegativeReals
    )
```

Implementation – oemof.solph.flows._invest_flow

```
for i, o in self.CONVEX_INVESTFLOWS:
    lifetime = m.flows[i, o].investment.lifetime
    interest = m.flows[i, o].investment.interest_rate
    if interest == 0:
        warn(
            msg.format(m.discount_rate),
            debugging.SuspiciousUsageWarning,
        )
        interest = m.discount_rate
    for p in m.PERIODS:
        annuity = economics.annuity(
            capex=m.flows[i, o].investment.ep_costs[p],
            n=lifetime,
            wacc=interest,
        )
        investment_costs_increment = (
            self.invest[i, o, p]
            * annuity
            * lifetime
            * ((1 + m.discount_rate) ** (-m.es.periods_years[p]))
        )
        investment_costs += investment_costs_increment
        period_investment_costs[p] += investment_costs_increment
```

Lifetime logic

- P: installed capacity; p: period; n: lifetime

$$P_{total}(p) = P_{invest}(p) + P_{total}(p-1) - P_{old}(p) \quad \forall p > 0$$

$$P_{total}(p) = P_{invest}(p) + P_{existing} \quad \forall p = 0$$

$$P_{old,end}(p) = P_{invest}(p-n) \quad \forall p \geq n$$

$$P_{old,end}(p) = 0 \quad else$$

$$P_{old,exo}(p) = P_{existing} \quad \forall p = n - age$$

$$P_{old,exo}(p) = 0 \quad else$$

$$P_{old}(p) = P_{old,end}(p) + P_{old,exo}(p)$$

total (installed) cap: previous cap + installations - decommissionings

Decomissionings

- endogeneous plants: installations that happened in the period the plants lifetime ago
- exogeneous plants: decommissioning of existing capacity in period lifetime – (initial) age
- Total decommissioning: sum of endogeneous and exogeneous decommissioning

Handling cost values (1/2)

- In general: all cost values may vary on a **periodical basis**, but shall be fixed within a period.

- Cost values have to be provided **in nominal terms**.
  - Calculating real values and annuities takes place under the hood.

- **Annuities and discounting**
  - A **discount_rate** is given on a **model-wide basis**. It reflects inflation.
  - An **interest rate may be given per component / flow** (asset) that can be invested in. It can deviate from the discount_rate, e.g. to take an investor‘s view and demand for higher interest rates.
    If a social planner perspective is taken, the interest_rate should be equal to the model‘s discount_rate, which is the default.
  - Annuities are calculated under the hood (next slide).

Handling cost values (2/2)

- Cost terms for MultiPeriodInvestment objects (or other components that is invested in)

CAPEX: investment annuities

$$P_{invest}(p) \cdot annuity(c_{invest}(p), n, i) \cdot n \cdot DF(p) \quad \forall p \in PERIODS$$

$$annuity(c_{invest}(p), n, i) = \frac{(1+i)^n \cdot i}{(1+i)^n - 1} \cdot c_{invest}(p)$$

- P: installed capacity
- p: period
- n: lifetime
- i: interest rate
- DF: discount factor

Fixed costs

$$\sum_{pp=p}^{p+n} P_{invest}(p) \cdot c_{fixed}(pp) \cdot DF(pp) \cdot DF(p) \; \forall p \in PERIODS$$

with discount factor

$$DF(p) = (1+d)^{-p}$$

Outlook

- Pending PR: https://github.com/oemof/oemof-solph/pull/828
  - Functional and complete
  - Already usable via `pip install git+https://github.com/oemof/oemof-solph.git@features/multi-period`
  - Merge conflicts currently resolved; CI tests working (except for issue with report to coveralls)

- Timeline
  - To be integrated in v0.5.1
  - Support for new developments (e.g. components) can be provided by J. Kochems
    → actually, it is just changing the indexing here: add a periods, timesteps indexing for flows (p, t)

Contact

Johannes Kochems

research associate at DLR, Institute of Networked Energy Systems, Stuttgart |
PhD candidate at Technical University of Berlin

E-Mail:
johannes.kochems@dlr.de
kochems@campus.tu-berlin.de

GitHub: jokochems