SMS of simplified cn_liquid model

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Note: The SMS documented here is based on the SMS of the cn_ptl model of Sep. 17, 2021 (see the cn-ptl repo, .../prototype/docs). This SMS has been implemented in pyomo as the *cn_liquid v.1.0* model. Whenever modifications of the model will be desired, this document will be kept consistent with the pyomo model implementation.

1 Symbolic model specification (SMS)

The SMS documents all model entities (indexing structure, variables, parameters, relations). This draft presents SMS of incomplete model prototype being implemented in Pyomo for testing Pyomo implementation and reporting module. The prototype will be gradually extended and use in the corresponding MCMA.

1.1 The model purpose

The model aims at supporting analysis of the relations between the decisions on the technology portfolio (investment for capacity expansion and activity-levels) for producing liquid fuels, and the consequences of implementation of such decisions. The consequences are measured by values of the outcome variables that represent conflicting objectives, such as costs and externalities.

1.2 Indexing structure

1.2.1 Model configuration

Model instances corresponding to this SMS are generated based on the values in a data set, except of two configuration parameters defined in the SMS, namely:

- *periods*: number of planning periods, and
- *lifet*: number of planning periods in which the newly installed capacity remains available.

1.2.2 Indexing structure of the model

The model uses the following indices and the corresponding sets:

- $p \in P$: the ids of the 5-year planing periods; e.g., for *periods* = 7, $P = \{0, 1, 2, \dots, 6\}$.[1]
- H: set of previous, immediately before the first planning[2] periods. If the newly installed capacity is available only in the vintage period, i.e., $lifet = 0$, then H is an empty set. For $lifet > 0$ it is defined by $H = RangeSet(-lifet, -1)$.[3] For example, for $lifet = 3$, $H = \{-3, -2, -1\}$.

[1]Instead of using the calendar-year values, we use sequence of positive integer values, i.e., for the calendar years {2020, 2025, ..., 2050} we index the planning periods by non-negative integer numbers. The correspondence between the planning periods and the calendar years can be defined (for reporting) by a simple mapping.

[2]First planning period is indexed by 0.

[3]Note the difference between $RangeSet(1, 3)$ and the sequence returned by the standard Python function $range(1, 3)$. The first one has three elements, while the second has only two elements.

- $v \in V,\ V = H \cup P$: vintage period (i.e., period in which the newly installed capacity becomes available). In other words, in a current period the available capacities consists of:
  - new capacity installed in the current period, and
  - new capacities installed in each of the $lifet$ periods immediately before the current period.

  Therefore, negative indices of V correspond to historical periods (prior to the first planning period); the capacities installed in these periods can still be used during the planning periods.
- $(p, v) \in V_p$ (the set is denoted in the pyomo implementation by VP): two-dimensional set of all feasible pairs of p and v indices.
- $t \in T$ technologies: e.g., $T = \{\mathrm{OTL}, \mathrm{CTL}, \mathrm{BTL}, \mathrm{PTL}\}$ or $T = \{\mathrm{OTL}, \mathrm{PTL}\}$.
- $f \in F$: final commodities (products), i.e., liquid fuel. E.g., $F = \{\mathrm{gasoline}, \mathrm{diesel-oil}\}$ (if demand is defined for each type of liquid fuel) or $F = \{\mathrm{fuel}\}$ (if demand is defined for an aggregate of all considered fuels).

1.3 Variables

Although all variables are treated equally within the model, we divide the set of all model variables into categories corresponding to the roles; this helps for structuring the model presentation.

1.3.1 Decision variables

The technology portfolio is implied by values the decision (control) variables:
- $ncap_{tv}, t \in T, v \in P$: new production capacity of t-th technology, made available at the beginning of v-th period.[4] The capacity that is "new", and available, in v-th period remains available in $lifet$) following periods.[5] Note that the capacities installed in historical periods are defined by the model parameters.
- $act_{tpv}, t \in T, (p, v) \in V_p$: activity level of t-th technology, using in period p the new capacity provided in period v.

1.3.2 Outcome variables

Outcome variables are used for evaluation of the consequences of implementation of the decisions; therefore, at least one of them is used as the optimization objective.

In the model prototype only three outcomes (to be used used as criteria in multiple-criteria model analysis) are defined:
- $cost$: the total cost of the system over the planning period,
- $invCost$: the investment costs of new capacities, and
- $omCost$: the O&M (operations and maintainance) costs, and
- $co2$: the total CO2 emission caused by the production system.

1.3.3 Auxiliary variables

All other variables used in the SMS:
- $omcVar$: variable part of $omCost$

[4] We use single-letter indices, which allows for the compact notation, i.e., $ncap_{tv}$ instead of $ncap_{t,v}$.
[5] In former model versions life-periods lt were denoted by τ.

- $omcFixP$: fixed part of $omCost$ related to the capacities installed in planning periods,
- $omcFixH$: fixed part of $omCost$ related to the capacities installed before planning periods,
- $omcFix$: total ($omcFixP + omcFixH$) fixed part of $omCost$

1.4 Parameters

The following model parameters are used in the model relations specified in in Section 1.5:

- dis_p: discount rate
- $hncaph_{tv}, v \in H$: new capacities installed in historical periods,[6]
- d_{fp}: demand for final commodities defined (fuel),
- $a_{tvf}, v \in V$: amount of output from the unit of the corresponding activity,
- $cuf_{tv}, v \in V$: capacity utilization factor
- $invC_{tv}, v \in P$: unit investment cost of new capacity
- $vom_{tv}, v \in V$: variable O&M costs,
- $fom_{tv}, v \in V$: fixed O&M costs,
- $ef_{tv}, v \in V$: CO2 emission factor

1.5 Relations

The values of the model variables conform to the following model relations.

1. The sum of activities act_{tvp} shall result in producing the required amounts of the final commodities:

$$\sum_{t \in T} \sum_{v \in V_p} a_{tvf} \cdot act_{tpv} \geq d_{fp}, \quad f \in F,\ p \in P,\ (p, v) \in V_p. \tag{1}$$

2. The levels of activities cannot exceed the corresponding available capacities. This relation holds for two situation, namely, when the capacity is defined by either the decision variable (then $v \geq 0$) or by the $hncap$ parameter ($v < 0$), respectively. Therefore, the corresponding relation is generated in either (2) or (3) form:

$$act_{tpv} \leq cuf_{tv} \cdot ncap_{tv}, \quad t \in T,\ p \in P,\ (p, v) \in V_p,\ v \geq 0, \tag{2}$$

$$act_{tpv} \leq cuf_{tv} \cdot hncap_{tv}, \quad t \in T,\ p \in P,\ (p, v) \in V_p,\ v < 0. \tag{3}$$

3. Investment costs of new capacities are defined by:

$$invCost = \sum_{t \in T} \sum_{v \in P} dis_p \cdot invC_{tv} \cdot ncap_{tv} \tag{4}$$

4. Operations and maintenance costs, defined by (5), consists of two parts, namely the variable costs (6), and the fixed (implied by the installed capacity) costs, see (7):

$$omCost = omcFix + omcVar \tag{5}$$

$$omcVar = \sum_{t \in T} \sum_{p \in P} dis_p \sum_{(p,v) \in V_p} vom_{tv} \cdot act_{tpv} \tag{6}$$

[6] For the sake of brevity, iterators $f \in F, p \in P$, and $t \in T$ are further on omitted, whenever these are obvious.

$$omcFix = omcFixP + omcFixH \tag{7}$$

The fixed O&M costs are related to the capacities installed in the planning periods (the model variable) and to the capacities installed in historical periods (which are given). These two components are represented by (8) and (9), respectively.

$$omcFixP = \sum_{t \in T} \sum_{p \in P} dis_p \cdot fom_{tp} \cdot ncap_{tp}, \tag{8}$$

$$omcFixH = \sum_{t \in T} \sum_{p \in P} dis_p \sum_{v \in H} fom_{tv} \cdot hncap_{tv}. \tag{9}$$

5. Total cost is defined by:[7]

$$cost = invCost + omCost \tag{10}$$

6. The total CO2 emission caused by the activities is defined by:

$$co2 = \sum_{t \in T} \sum_{p \in P} \sum_{v \in V_p} ef_{tv} \cdot act_{tvp} \tag{11}$$

Note: entities describing the up-stream technologies should be researched and added to the SMS in a future version of the model. Then eq. (11) shall be modified accordingly.

[7] Costs of inputs shall be added after clarification how it relates to the $omCost$.