Accommodating fairness in a shared-energy allocation problem with uncertainties

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With the recent emergence of prosumers (who are both energy producers and consumers), some companies propose to aggregate prosumers in the energy market. This is because prosumers are generally too small to directly enter the electricity market themselves. To implement those aggregators, there is a practical need to study how those who compose the portfolio, based on their assets and production/consumption profiles, are going to be treated fairly. We discuss ways to accommodate fairness by design in the modeling of the problem.

First, we propose the following model of an aggregator in charge of N prosumers. We denote $x := (x_1, \dots, x_N)$ the set of variables where x_i are the decisions concerning prosumer i. The technical constraints of prosumer i are represented through feasible set $\mathcal{X}_i$, and the market constraints on market exchanges $M_i x_i$, common to all prosumers, are represented with feasible set $\mathcal{M}$. The aggregator accesses the energy market as one, and its energy exchanges are the aggregated exchanges of prosumers $\sum_i M_i x_i$. Then the aggregated model is as follows:

$$
\begin{aligned}
(A) \qquad \underset{x}{\text{Min}} \quad & f(x) && && (1a)\\
\text{s.t} \quad & x_i \in \mathcal{X}_i && \forall i && (1b)\\
& \sum_i M_i x_i \in \mathcal{M} && && (1c)\\
& x \in \mathcal{A} && && (1d)
\end{aligned}
$$

where eq. (1b) models the physical constraint of each prosumer i; eq. (1c) connects all prosumers and models the constraints on aggregated market exchanges; eq. (1d) models acceptability constraints, any solution of (A) must be in an acceptable set all prosumers have agreed on prior to optimization; finally, f is the objective function of the aggregator.

The conceptualization and practical implementation of fairness pose formidable challenges, particularly in optimization problems, for a complete review of the existing literature on fairness modeling, see [1]. In this work, we introduce various strategies for integrating fairness into optimization problems *by design*. We present two key elements for achieving fair allocation in an aggregation: first, we leverage traditional approaches involving objective functions such as the *utilitarian* f^U, *proportional* f^P [2] and *minimax* f^{MM} [3] objective functions.

$$f^U(x) := \sum_i f_i(x_i), \tag{2a}$$

$$f^P(x) := \sum_i \log[f_i(x_i)], \tag{2b}$$

$$f^{MM}(x) := \max_i \frac{(v_i - f_i(x_i))}{v_i}, \tag{2c}$$

where v_i is the optimal cost of prosumer i when operating alone, and $f_i(x_i)$ is the cost of agent i depending on decisions x_i.

Additionally, we introduce *acceptability constraints* through the set $\mathcal{A}$ which ensures that agents improve, in some predefined sense, their outcome within the aggregation. We consider that a contract cannot be deemed acceptable for a prosumer if they would be better off independently, and therefore propose the following acceptability constraints:

$$\mathcal{A} := \Big\{ f_i(x_i) \leq v_i, \quad \forall i \Big\} \tag{3}$$

These acceptability constraints are extended to dynamic and stochastic settings, allowing for risk-averse and time-consistent guarantees. As a result, our proposed model is well-suited for addressing inherent uncertainties within multistage stochastic programs, enhancing its practical applicability. Finally, we assess these different strategies on a toy model and provide a comprehensive analysis of the implications associated with each modeling choice.

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