A two-stage stochastic programming model for lot-sizing with onsite generation of renewable energy

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Industrial companies are increasingly under pressure to mitigate the CO2 and pollution emissions linked to their manufacturing activities. They are also confronted with a sharp rise in the price of conventional energy sources (gas, grid electricity...) so that the availability and affordability of energy is becoming a critical parameter in manufacturing. One way to deal with these two challenges consists in powering industrial processes with electricity generated on-site from renewable sources. However, the intermittence of renewable energy sources (wind, sun...) makes it impossible to accurately predict the amount of energy they will provide. Thus, an integrated energy supply and industrial production planning problem under uncertain renewable energy availability needs to be solved. As shown e.g. by the recent literature review [1], it seems that this problem has been scarcely studied until now. This work is thus an attempt at modeling and solving such a problem by using a two-stage stochastic programming approach.

Problem description and modeling We seek to plan production in an industrial plant producing several types of item to satisfy a time-varying external market demand without backlog. The plant comprises a single production resource. This resource may produce only one type of item at a time. Changing the type of item in production requires to carry out startup operations with fixed startup cost. Energy is consumed during both startup operations and manufacturing.

The energy supply system comprises three main elements : the onsite power generation devices (photovoltaic panels) converting a renewable energy source into electricity, the on-site energy storage system (a set of batteries) and the main electricity grid from which electricity may be bought at a given time-varying buying price. The amount of electricity produced by the onsite power generation devices depends on the availability of the corresponding energy source and is thus subject to many uncertainties.

We propose to model the resulting stochastic lot-sizing problem via a two-stage stochastic programming approach. This approach relies on the assumption that the energy supply planning decisions do not have to be made ”here-and-now” but may rather be postponed to a later point in time at which more detailed information about the actual amount of the generated green energy over the whole planning horizon becomes available. Thus, the first stage decisions consist of building a production plan for a single-machine multi-product system. To this aim, the planning horizon is divided into a set of planning periods sufficiently short to track the variations in the green energy availability and grid electricity buying price with the necessary accuracy. The resulting small-bucket lot-sizing problem is modeled as a Proportional Lot-sizing and Scheduling Problem (PLSP). The startup and lot-sizing decisions in the production plan translate in an energy demand for each period of the planning horizon.

A finite set of randomly generated discrete scenarios are used to represent the uncertainties on the available renewable energy. A scenario gives a potential realization of the quantity of energy generated by the PV (photovoltaic) panels for each period. The second-stage decisions thus consist of building, for each considered scenario, an energy supply plan capable of meeting the energy demand of the system in each period. For each scenario, this energy supply plan determines the amount of energy to be bought from the grid, stored in or retrieved from the battery at each time period.

This modeling approach results in the formulation of a single large-size mixed-integer linear program (MILP) in which all the energy generation scenarios are taken into account.

Solution approach and preliminary computational results The resulting MILP is solved by an L-shaped method. This approach decomposes the problem into a master problem and a set of linear sub-problems. The master problem comprises the first-stage production planning decisions and is thus an MILP solving a deterministic PLSP. Each sub-problem corresponds to a second-stage scenario and is a small linear program taking as input data the energy demand coming from the first-stage decisions and building a minimal-cost feasible energy supply plan.

More precisely, we develop a Branch-and-Benders-cut algorithm and implement three main strategies to accelerate its convergence. The first strategy is a node pruning method which consists of fixing the values of the binary variables at the current node and solving the corresponding LP problem. The corresponding objective value gives a local lower bound which can be used to prune the current node. Second, a primal acceleration technique called the in-out stabilization method [2] is used at the root node of the branch-and-bound tree. Finally, a set valid inequalities, derived from the classical (l, S) inequalities known for the uncapacitated single-item lot-sizing problem, are also added to the MILP formulation at the root node of the branch-and-bound tree.

For our computational experiments, 120 instances were randomly generated using data available in [3, 4]. The scenarios were generated as follows. First, for each time period, we randomly generated a value for the predicted photovoltaic (PV) generation quantity, by using a Gaussian process with means equal to the deterministic PV generation quantities given in [3]. Second, to reflect the fact that the errors in the predictions on the future PV generation often display strong time correlations, we used an auto-regressive model to generate, in each scenario, the amount of renewable energy available at each period of the horizon.

The algorithm was implemented in Python and each instance was solved with the mathematical solver CPLEX 20.10. We compare the computational performance of our Branch-and-Benders-cut algorithm with the one of CPLEX solving directly the whole problem as well as the one of a classical Benders approach. Our preliminary computational results show that for small-size instances (3 products, 48 periods) and medium-size instances (7 products, 64 -periods), comprising 100 or 500 scenarios, the proposed Branch-and-Benders-Cut algorithm outperforms the other two approaches in terms of both solution quality and computation time.

Références

[1] Kristian Bänsch, Jan Busse, Frank Meisel, Julia Rieck, Sebastian Scholz, Thomas Volling, and Matthias G. Wichmann. Energy-aware decision support models in production environments : A systematic literature review. *Computers & Industrial Engineering*, 159 :107456, 2021.

[2] Walid Ben-Ameur and José Neto. Acceleration of cutting-plane and column generation algorithms : Applications to network design. *Networks : An International Journal*, 49(1) :3–17, 2007.

[3] Matthias Gerhard Wichmann, Christoph Johannes, and Thomas Stefan Spengler. Energy-oriented lot-sizing and scheduling considering energy storages. *International Journal of Production Economics*, 216 :204–214, 2019.

[4] Hêriş Golpîra, Syed Abdul Rehman Khan, and Yu Zhang. Robust smart energy efficient production planning for a general job-shop manufacturing system under combined demand and supply uncertainty in the presence of grid-connected microgrid. *Journal of Cleaner Production*, 202 :649–665, 2018.