Integrated planning of biomass inventory and energy production

Marco Chiarandini[1], Niels H. Kjeldsen[1], and Napoleão Nepomuceno[2]

[1] University of Southern Denmark, Department for Mathematics and Computer Science, Odense, Denmark
{marco, nhk}@imada.sdu.dk

[2] Universidade de Fortaleza, Programa de Pós-Graduação em Informática Aplicada, Fortaleza, Brazil
napoleaovn@unifor.br

We consider an integrated biomass logistic and energy production problem that arises in long term planning for scenario analysis in the energy sector. It encompasses two decision stages in a national system: one on the purchase of biomass from suppliers and one on the specific production of electricity and heat of each power plant.

The rising interest of citizens in environmental issues and the global economical changes push the political class to design incentives, such as an increase of the price of CO_2-emissions, to the use of biomass fuel instead of fossil fuels as a source of energy. Biomass logistics however requires special considerations in storage and transportation. A typical biomass fuel substitute for coal are wood pellets, which should be kept dry — since moisture starts a process that can lead to self ignition. This leads to limited storage capacity in silos or storehouses that are expensive to build. The consequence is, that in case of ordinary but uncertain events, such as delayed deliveries and demand fluctuations, there is a higher risk of a fuel shortage or fuel overflow.

Biomass delivery contracts with external suppliers are decided one year in advance. To decide upon them and achieve important savings the management would like to have aiding tools to look ahead into the foreseen overall electricity and heat production costs, including costs for biomass shortage and overflow. Such tools can also be helpful in economic evaluations of strategic investment decisions, such as modernizing a plant or increasing its local biomass storage capacity.

Once contracts are fixed, the energy production part of the biomass logistic problem is similar to the well studied unit commitment problem [2]. The integrated biomass logistic problem however includes fuel level management and decisions on fuel contracts that, to our knowledge, have not been treated in the literature and complicate even further the problem. We model the integrated problem as a mixed 0-1 integer linear programming problem and treat the uncertainty of future data with multiple scenarios. In spite of the intrinsic computational intractability of this long term planning problem we seek for efficient solution algorithms that could make it possible to easily test several alternative choices in settings.

We treat the problem as a two-stage stochastic optimization problem and consider separately contract decisions and energy production decisions. The latter are scenario dependent and can be updated recursively. In our search for fast but good solutions we relax the integrality constraints on the variables of the look-ahead energy production problem thus obtaining an approximated solution of the integrated problem. Further, we study a problem decomposition to take advantage of the possible speedups offered by parallel computing systems. In particular, we apply a Benders decomposition, which has given important speedups in other cases of stochastic optimization in the energy sector [1,3,4]. In our case, we decompose the problem in an outer problem, where discrete variables represent the choices of contracts to be purchased, and an inner problem, in which we minimize operational costs. The inner problem presents a block angular structure, where the contract decisions bind the different scenarios together. If contract purchases are decided, the inner problem can be decomposed into multiple sub problems one per each scenario. Our inner problem is always feasible, thanks to under/overproduction slack variables, and bounded. Hence, only optimality cuts are generated from the dual LP solution of the inner problems.

We studied two implementations of the Benders procedure: a classical approach that solves the outer problem to integrality and re-builds the search tree after every solution of the inner problem and a modern approach that takes advantage of callback functions and integrates the solution of the sub problems and the addition of Benders cuts at each node of the search tree of the outer problem.

The computational experiments are based on CPLEX as ILP solver and are conducted on a cluster of computers with 8 processing units per node. The use of the cluster allowed us to test the impact of different features and scales of the input data. The results indicate that the solution to the overall problem with all binary variables is possible only for instances with one single scenario and a coarse-grained time discretization. On the other hand, our approximated solution by relaxation of the binary variables in the inner problem allows us to include several scenarios and a finer granularity in the data thus providing overall cost predictions for much more realistic instances. The quality of these predictions is of similar quality as those obtained by the full integral model when compared on simplified instances.

As far as the contribution of Benders decomposition is concerned, the two implementations are not able to improve the direct solution of the approximated model by the ILP solver in spite of the fat that they are better at using parallel processing units. An explanation to this result might be that the ILP solver is already able to exploit the advantages of a parallel computing environment better than the scenario decomposition provided by Benders. Further improvements on the Benders procedure implemented are however possible.

References

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