Optimal Design of Hydrogen Supply Chains by a Multiobjective Evolutionary Algorithm Based on Decomposition (MOEA/D)

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1 Introduction

Hydrogen is expected to play a significant role in low-carbon energy landscape : according to the Hydrogen Council, hydrogen will cover 18% of global energy demand by 2050. Much of the future development of hydrogen will depend not only on upscaling and technological development (e.g. in electrolysis) but also on energy policies and hydrogen supply chain (HSC) deployment. Developing a cost-efficient infrastructure, encompassing the wide spectrum of production and distribution options that may evolve over time with developing demand is a significant challenge. In that context, the objective of the work is to efficiently support the design of sustainable hydrogen supply chains considering both economic and environmental concerns by appropriate multi-objective strategies.

This work follows the guidelines proposed in [1] in which the total daily cost (TDC) of the HSC is minimized, and also, as in [2], the global warming potential (GWP) indicator is considered as a second objective to be minimized. In both cited works the problem is modelled as a mixed integer linear programming (MILP) and solved by a deterministic algorithm (via the ε-constraint method for the biobjective formulation). The geographical area is divided into several “grids” (nodes), where hydrogen demand must be satisfied. The decision variables involve the number, location and capacity of production plants and storage facilities to be set up in each geographical area (grid). Besides, the selected transportation links within the network, their corresponding flowrates, as well as the hydrogen plant production rates, have also be determined. The model also considers that hydrogen may be produced either by electrolysis or from gasification.

Yet, the size of the problem mainly induced by the number of binary variables often leads to difficulties for problem solution and the treatment of large problem instances can be viewed as a challenging issue from a numerical viewpoint. To overcome these barriers, the solution of this problem is addressed here through a multiobjective evolutionary algorithm, namely MOEA/D. This recent decomposition-based algorithm enables to obtain the Pareto front in one single run as each individual in the population solves a specific parametrized scalar optimization sub-problem, i.e., every individual can be seen as an agent searching a specific region of the search space. In addition, differential evolution algorithm (DE) is used as the embedded search engine. In order to obtain efficient results for larger instances, MOEA/D is coupled with a local search procedure : the integer variables (number of production plants) are set to values provided by the evolutionary algorithm while a Linear Programming (LP) solver, devoted to transportation problems, determines the optimal flows between grids as well as the production rate for each plant. In other words, the original MILP problem is solved by a master-slave strategy where the evolutionary algorithm (master) manage only integer variables, while the LP solver (slave) treats the continuous variables as well as the constraints.

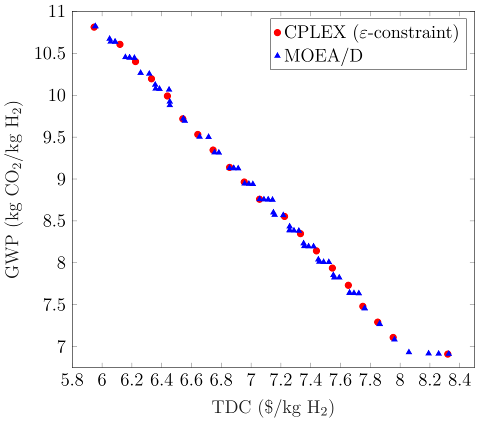

FIG. 1 – Obtained Pareto front for both approaches.

In this study, the Midi-Pyrénées territory in France is considered taking into account 8 grids. For the sake of comparisons, the problem is also solved by a mathematical programming (MP) technique, namely CPLEX. For the MOEA/D algorithm, the Tchebycheff approach is used as the scalarizing function, with a population size of 20 individuals and a maximum number of generations of 500. For CPLEX, the ε-constraint approach is considered using 20 uniformly distributed constraint points. The obtained Pareto front are shown in Figure 1. As can be seen, solutions of same quality are obtained with both approaches, however, the MOEA/D algorithm was able to found more non-dominated solutions (72) than the exact method. The hypervolume metric is computed for both approaches (for MOEA/D, the median of 11 runs is presented). As can be noted, the proposed hybrid approach outperforms the classical strategy. Besides, there is a significant difference of required computational time for both approaches, as seen in Table 1.

	CPLEX	MOEA/D
Non-dominated solutions	20	72
CPU time (s)	5487.5	31.1
Hypervolume	5.3627	5.5308

TAB. 1 – Numerical results of both approaches

2 Conclusions and perspectives

The evolutionary approach proved to be efficient for solving this kind of problems and produces a very good approximation to the Pareto front. This is promising for the solution of larger size instances, for which MP techniques might not be adequate. In a future work, a more realistic (nonlinear) model of the HSC is to be considered, taking thus full advantage of an evolutionary approach.

Références

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