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Optimizing industries' power generation assets on the electricity markets

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HIGHLIGHTS

- Adaptive model to size the opportunity for coupling energy-intensive plants with electricity markets.
- Mixed binary-continuous linear optimization problem.
- Assessment of optimal power management in refinery plants.
- Energy efficiency opportunity to implement Waste Heat Recovery in cement plants.

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ABSTRACT

For historical reasons, many large industrial sites have their own power generation units, either because the site was isolated when it was built or because the local network was not reliable enough to ensure regular production. This can apply to energy-intensive industries like refineries or LNG plants in the Oil & Gas sector, but also to mining plants, metal industries and chemical plants. These generation assets are usually operated in a suboptimal way, the only concern being the safety of the process. The focus of this work is to determine how industrial plant operators can make optimal use of these assets, considering interactions with the electricity markets.

Based on the mathematical description of this optimization problem, a model achieving a double target is introduced. First, to develop a standard architecture that can be easily translated from one case to another. Then, to assess the maximum expected savings and the induced strategy. This model is applied to a refinery case study, where expected earnings are as much as €8 M per year and account for 1% of turnover. The figures obtained show that this is a relevant business concept. Following this trend, the potential to implement Waste Heat Recovery in energy-intensive cement plants is considered.

1. Introduction

Over time, energy management issues are becoming increasingly important, set to a backdrop of expensive and scarce resources, an uncertain geopolitical climate and rising environmental concerns [1,2]. Following the trend for optimal energy management, the case of electricity assets owned by regular industrial sites merits attention. Indeed, for historical reasons, many large industrial sites have their own power generation units, either because the site was isolated when built or because the local network was unreliable enough not to jeopardize regular production. This situation mostly involves energy-intensive industries, such as iron/steel or other metal industries, foundries, paper mills, cement plants, mining or Oil & Gas fields, chemical plants – and in particular petro-chemical plants including refineries or LNG plants, and even glass industries. Production units of this type are currently managed by local operators whose main goal is to ensure the industrial site's production. The decision process for satisfying demand is thus often based on the operators' experience and safety concerns, which can easily lead to sub-optimal solutions. In particular, this can result in a situation whereby many production units function below their rated operations, leaving an unexploited potential for energy savings, earnings or environmental purposes [3–7]. Our contribution differs from previous asset management analysis as it aims to take advantage of the interaction with the electricity markets in an optimization framework dedicated to decision-makers, without changing the plant's capital-intensity.

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In that sense it extends [8,9] as it is closed to a *unit commitment*-type problem.

In order to determine an optimal use for these electricity generation assets, we consider producers that play a role in electricity markets. Indeed, as these capacities are currently used sub-optimally, putting the focus on interactions with the markets could be an interesting way to try and manage them more profitably and hence generate extra earnings. The problem statement is the following:

> Considering an energy-intensive industrial site (*e.g.*, refinery, cement plant) with its own electricity generation assets, considering interactions with spot markets (sales and purchases), and taking into account operational constraints driven by the production plan and constraints from the Transmission System Operator (TSO), what earnings could industrials attain from the optimal use of their assets?

The approach for this study will be the following. We will design an adaptive model relying on the mathematical description of an optimization problem. This will then be tested on two customer cases: a refinery (Section 3.1) and a cement plant (Section 3.2), to find out whether the idea itself is relevant or not, *i.e.*, whether the expected savings are significant or negligible. In addition, attention will be paid to the adaptability of the mathematical model to ascertain whether it is easily applicable to a wide variety of case studies.

This study is not dedicated to making a "from scratch" design of own generation capacity for an energy-intensive industrial plant based on operational and TSO constraints: In that sense this work does not consist in an *asset management*-type problem [10,11]. Conversely, the goal is to determine an optimal solution to:

- Manage previously-invested assets sized for an isolated management team to consider a future connection to the power grid (Section 3.1); or
- Take advantage of energy efficiency refurbishment of an existing plant (Section 3.2).

2. Towards an adaptive model

The model should be suitable to provide the two following outputs:

- The amount of potential earnings, to see if this option is relevant or not and might be worth investing in.
- The guidelines on how these earnings would be achieved. The goal is not to develop a piloting tool that would inform the industrial site at any moment how to adapt its production, because this would require a thorough analysis of the specifics of each site, whereas we want our model to be easily adaptable from one case to the other. However, to show that solutions are realistic, the model must still give an idea of how these earnings would be made and what the production curve of each machine would look like.

The following approach will be adopted:

- We will start by developing an adaptable model, *i.e.*, choose a generic architecture and define the mathematical problem associated with this structure. We will then encode it using Python language and the Gurobi solver [12]; then
- We will test the adaptability of the model and the concept at stake on two user cases: a refinery (Section 3.1) and a cement works (Section 3.2).

2.1. Model architecture

Fig. 1 provides the architecture of the model. This consists in an industrial site with local production, electricity generation assets, a real or hypothetical connection to the wholesale markets, and an input requirement. The plant potentially uses both steam and electricity flows, and we will assume that the fuel supplied is gas. We will therefore have 3 types of flow: electricity, steam and gas (for the boiler and gas turbines). The final flow "industrial product" is simply there to ensure that industrial production is maintained throughout our optimization. We consider three types of machine: boilers, gas turbines and steam turbines. The idea will be to adapt the level of production of each of these machines and the level of sales and purchases from the spot market to save money. We also add the possibility of recycling some of the industrial products, as this could be relevant in the Oil & Gas sector for instance.

The earnings come from the optimal values for the sale and purchase flows (right, blue) and for the gas purchases (bottom, green). After running the program in two modes, *i.e.*:

1. the *island* mode, where the site is isolated and does not sell or purchase any electricity from the markets. Some specific constraints fix the values of these flows at 0;
2. the *satellite* mode, where the industrial site interacts with the markets.

The savings will be determined as the difference between the two energy bills generated.

Although this problem is close to cogeneration, we must stress that here, the choice is made between producing more electricity from either steam, gas or the markets. The choice is not simply between whether to produce more heat or more electricity.

Attention is paid to the modularity of the model in order to adapt the configuration of the system easily, particularly:

- The number of boilers, gas turbines and steam turbines.
- The yields of each machine (this will however have to be either continuous or piecewise-continuous).
- The week of the year, and hence the level of electricity prices.

2.2. Mathematical description

This model lays on a mixed binary-continuous linear optimization problem [13], the main notations of which are summarized in Table 1. In Fig. 1, each of the arrows is actually a continuous variable, and each of the boxes a set of constraints. The flow variables are continuous, and the decision variables are the sales and purchases on the markets and the gas purchases [14]. The objective function can hence be written in the equation involving prices (p), commission fees (p_{fee}) and quantities exchanged on the market (q):

$$\max \sum_{t=0}^{t_f} \left(q_{\text{sales},t} \times \left(p_{\text{elec},t} - p_{\text{fee},t}\right) - q_{\text{purchase},t} \times \left(p_{\text{elec},t} + p_{\text{fee},t}\right) - q_{\text{gas},t} \times p_{\text{gas},t}\right) \tag{1}$$

with the following assumptions:

Nodal constraints: Which state that at each node of the scheme (Fig. 1), the input flows equal the output flows.

Production constraint: The optimization problem is driven by the plant production – for instance the refined products in a refinery – which has to be guaranteed. This production constraint is introduced as the plant revenue is provided mainly by its production process. Hence there is no possible