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Energy Allocation in France, Midterm Report

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1 Introduction

In this project, we are trying to model different instances that France's electrical production could face over the next years. For some context: most of the time, France has a positive electrical production balance (thanks to its nuclear park) and usually exports some of its energy to neighboring countries. However, if the cost of producing energy in neighboring countries is cheaper, France can import it as well.
In general, France's neighboring countries are not energy independent: for instance, since Germany stopped using their nuclear plants, an important part of Germany's gas has been imported from other countries, including Russia. Ever since the latter invaded Ukraine, there has been a lot of uncertainty on the European energy market and even more for the upcoming winter: as for example, Germany, Luxembourg, Italy and Belgium used to be heavily reliant on Russian gas.

Consequently, we have narrowed down these instances to three main ones, each having slightly varying constraints:

- Baseline: France has a duty to its citizens to provide stable electricity through its network throughout the year. As an electricity crisis is often linked to social unrest, we will tighten that constraint so that the government must prioritize its citizens.
- France is part of the European Union and, hence, has a duty to help their neighbors in case of energy crisis. The UK recently announced that, if February 2023 is as cold as February 2018, they would have to perform daily electricity cuts. In that sense, we will explore an instance where France has to export more energy than usual and thus push further its production capacities.
- Besides the current very short term energy crisis, France is also looking at having a greener energy production, even more so in the context of COP27, and with that comes the problem of non renewable sources of energy (fuel, coal, gas), which we can penalize in another instance.

2 Problem Formulation

2.1 Sets

- $t = 1, ..., T$: steps of 30 minutes
- $s = 1, ..., m$: sources of energy in France
- $p = 1, ..., n$: other countries (UK, Belgium etc.)

2.2 Parameters

The time span chosen for this analysis covers the year 2020 and the first semester of 2021: a total of 18 months. There are $m = 8$ sources of energy studied: nuclear, hydraulic, wind, solar, bioenergy, gas, fuel and coal. There are $n = 5$ neighbouring countries with daily import and export with France: Spain, UK, Italy, Switzerland and Germany-Belgium (as one).

In France

- $P_{s,t}$: production capacity of source s at time t (in MWh)
- $c_{s,t}$: economic cost of producing 1 MWh of energy from source s at time t
- $f_{s,t}$: environmental cost of producing 1 MWh of energy from source s at time t
- D_t: demand of energy at time t (in MWh)

Import/Export

- $E_{p,t}$: total export demand from country p at time t (in MWh)
- $v^E_{p,t}$: price of exporting 1 MWh of energy in country p at time t
- $I_{p,t}$: total import availability from country p at time t (in MWh)
- $c^I_{p,t}$: economic cost of importing 1 MWh of energy from country p at time t
- $f^I_{p,t}$: environmental cost of importing 1 MWh of energy from country p at time t

Our goal is also to simulate different instances, and we might need additional parameters to model them:

Coefficients

- $\lambda_{s,t} \geq 0$: coefficient to penalize when going over maximum production capacity at time t
- $\alpha_{p,t} \in [0, 1]$: percentage of external demand from country p at time t that we need to satisfy
- $\beta \in [0, 1]$: percentage of importance to give to the environmental costs, compared to the economic costs

2.3 Decision Variables

- $x_{s,t}$: amount of energy produced from source s at time t
- $y_{p,t}$: amount of energy coming from country p at time t
- $z_{p,t}$: amount of energy given to country p at time t

2.4 Objective Function

The goal is to minimize costs, as follows:

$$\min_{x,y,z} \sum_{t=1}^{T} \left(\sum_{s=1}^{m} \left(x_{s,t}\left(\beta f_{s,t} + (1-\beta)c_{s,t}\right) + \lambda_{s,t}\left(x_{s,t} - P_{s,t}\right)\right) + \sum_{p=1}^{n} y_{p,t}\left(\beta f^{I}_{p,t} + (1-\beta)c^{I}_{p,t}\right) - z_{p,t}\, v^{E}_{p,t} \right) \tag{1}$$

- $x_{s,t}\left(\beta f_{s,t} + (1-\beta)c_{s,t}\right)$: aggregated cost of producing energy from source s at time t
- $\lambda_{s,t}\left(x_{s,t} - P_{s,t}\right)$: Lagrangian penalization of going over production capacity for source s at time t.
- $y_{p,t}\left(\beta f^{I}_{p,t} + (1-\beta)c^{I}_{p,t}\right)$: aggregated cost of importing energy from country p at time t
- $z_{p,t}\, v^{E}_{p,t}$: aggregated revenue of exporting energy to country p at time t

This objective function represents the multi-objective problem. The objective function for our baseline model is similar, but with $\beta = 0$.

2.5 Constraints

Depending on the instance

- Prioritize France: $\sum_{s=1}^{m} x_{s,t} + \sum_{p=1}^{n}(y_{p,t} - z_{p,t}) \geq D_t,\ \forall t = 1, ..., T$
- Max import availability: $y_{p,t} \leq I_{p,t},\ \forall p = 1, ..., n,\ \forall t = 1, ..., T$
- Max export demand: $z_{p,t} \leq E_{p,t},\ \forall p = 1, ..., n,\ \forall t = 1, ..., T$
- Helping Neighbours: $z_{p,t} \geq \alpha_{p,t}\, E_{p,t},\ \forall p = 1, ..., n,\ \forall t = 1, ..., T$

These constraints mean that:

- Our own country (France) will be prioritized.
- We cannot import more than what is available.
- We cannot export more than neighboring countries' demands.
- We might have to help neighbours (due to European energy treaty).

Practical

- $x_{s,t} \geq 0,\ \forall s = 1, ..., m,\ \forall t = 1, ..., T$
- $y_{p,t} \geq 0,\ \forall p = 1, ..., n,\ \forall t = 1, ..., T$
- $z_{p,t} \geq 0,\ \forall p = 1, ..., n,\ \forall t = 1, ..., T$

3 Methods

We have a specific method for each instance, using Julia with Gurobi optimizer:

- **Baseline**: straightforward linear optimization.
- **Winter Crisis**: still linear optimization with the helping neighbours constraint. The latter can be varied to model different levels of crisis in neighbouring countries.
- **Long-Term Greener Energy**: this is a multi-objective problem. We will use multi-objective linear optimization using a weight-based approach to balance between economic and environmental objectives.

4 Data

The 2020 Réseau de Transport d'Électricité or RTE (electricity transmission system operator of France) dataset contains more than 35,000 rows of 15 minutes intervals of energy consumption, energy production per source, imports and exports to neighboring countries.

The production capacity $P_{s,t}$, demand D_t, export demand $E_{p,t}$ and import availability $I_{p,t}$ come from the french company RTE. For all this data, RTE gives what has been consumed for a given time t. Except for demand D_t, we will consider them as capacity values for our problem, which are not tight and can be extended using synthetic tolerance/percentage. Indeed, we can consider that capacity is not maximal, as RTE confirmed in their latest press release, and hence add a +15% of capacity over the actual consumption. Similarly for export demand and import availability, we can also push those values to +5%.

The costs and prices ($c_{s,t}$, $c^I_{p,t}$, $v^E_{p,t}$) are quite stable (for example, the nuclear energy cost is very stable along the year). We have real-world intervals of energy production costs that we will sample from. The import and export costs are less granular because they are not regular.

The $\alpha_{p,t}$ parameters are synthetic data that will be based on real-word information, looking into European energy treaties, and that will be manually varied to represent the intensity of the crisis.

The environmental costs ($f_{s,t}$ and $f^I_{p,t}$) will be based on the notion of Eco-cost, which includes multiple factors: resource depletion, Eco-toxicity, human health and carbon footprint. These costs are estimated in dollars and their data is available thanks to the Idemat international database. The β parameter will be manually varied to represent the importance we want to give to the social cost of production.

5 Expected Results

Results to observe, depending on the instance

- For our baseline model, we expect a lower overall economic cost than what the RTE data shows.
- For our crisis case, we expect the overall economic cost to increase with the intensity of the crisis. The cost might be very high but we expect it to be reasonable. We will try to compare with real-world budgets.
- For the sustainability case, we expect a penalization of non renewable energies. We think that the penalization on the overall economic cost will remain reasonable while decreasing significantly the amount of non renewable energies. We will use the Pareto curve function to find a good balance between both objectives.

6 Roles and Responsibilities

Oscar is responsible for the formulation of the problem and the gathering and estimation of the eco-cost data specifically. Hermine is also responsible for the formulation of the problem and the deeper research into overall data: which data sources, what assumptions makes sense, and discussion with an energy expert to validate assumptions.
Overall, we are working closely together to propose a viable resource production and allocation scheme under environmental and shortage constraints, using appropriate and tractable optimization methods.