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Abstract volume

Commodities and Energy Market Organization in the Energy Transition Context (EM 2018)

Rueil-Malmaison ■ France
18 - 19 June 2018

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Context and objectives

The energy industry is facing significant challenges: commodity markets are evolving rapidly and the various players have to deal with uncertainties surrounding additional investment requirements and new technological solutions, both in line with environmental policies and the energy transition process around the world.

Companies need to develop a strategic view of energy issues and they are reinventing their roles in increasingly interlinked markets. The high prices observed in the energy and non-ferrous metals markets during the last decade have been replaced by low prices and uncertainty.

The peak oil debate has given way to developments related to peak demand. Rare earth and lithium prices are increasingly at the center of the environmental policy debate.

In the gas and power industries, there is a pressing need to design the market rules capable to jointly support flexibility, meet the consumer needs, deliver a secure system and foster market integration. Recent events have generated additional uncertainty in the already complex and rapidly evolving global energy environment in which new actors and emerging economies are playing a leading role. Political developments around the globe are reshaping the geopolitical situation: market rules need to be reconsidered, as do the energy policies of governments at local, national and international level.

It is against this background that IFPEN proposes a conference on the organization of the commodity and energy markets (**EM 2018**).

EM 2018 will examine the strategies of industry within the evolving context of the energy transition and commodity market changes. The conference will present both theoretical and applied research and discuss new developments in the field of energy economics related to these themes.

Main scientific topics

- Energy Markets modeling
- Econometrics/Applied economics
- Operational Research

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PROGRAM

Monday 18 June

9:30 *Registration and welcome coffee*

10:00 **Opening of the conference**
E. Hache (EM 2018 scientific correspondent, IFPEN, France)

Welcome address
D. Houssin (CEO, IFPEN, France)

10:30-13:00 SESSION 1: ELECTRICITY MARKETS

Chaired by Clément Bonnet (IFPEN)

Keynote: Electricity and energy transition
R. Sioshansi (The Ohio State Univ., USA)

Coffee break

The supply of energy services: do local service providers use DSO or telecommunications network?
F-N. Bernal , C. Clastres (Univ. Grenoble-Alpes, CNRS, INRA, Grenoble-INP, GAEL, France)

Identifying electricity demand for residential consumers: a social, economic and technical analysis at the local level
M. Bordigoni, T. Verderi (Enedis, France)

On the viability of energy communities
I. Abada[1], A. Ehrenmann[1,2], X. Lambin[3] (1 ENGIE, 2 EPRG, 3 Toulouse School of Economics, France)

Questions and discussion

12:45 *Lunch*

14:30-17:00 SESSION 2: RAW MATERIALS IN THE ENERGY TRANSITION CONTEXT

Chaired by Emmanuel Hache (IFPEN)

Keynote: Dynamic modeling and raw materials
O. Vidal (ISTerre, Univ. Grenoble-Alpes, France)

The urban mining as a solution for the supply of critical minerals
R. Danino-Perraud (BRGM, Lab. d'économie d'Orléans, France)

Does lithium really matter for the electrification of the transportation sector?
E. Hache, G. Seck, M. Simoen (IFPEN, France)

Market or not market? Ensuring rare earth security of supply for the defense sector
A. Palle (IRSEM, France)

Copper and the energy transition context
C. Bonnet, E. Hache, G. Seck, M. Simoen (IFPEN, France)

Questions and discussion

17:00 *Coffee break*

17:30-18:30 SESSION 3: NEW NATIONAL OR INTERNATIONAL ENERGY ISSUES

Chaired by Benoît Chèze (IFPEN)

Allocating provincial CO_2 quotas for the Chinese national carbon program
M. Jiang[1], B. Zhu[1], J. Chevallier[2,3], R. Xi[4] (1 Jinan Univ, China ; 2 IPAG Business School, IPAG Lab. ; 3 Univ. Paris 8, LED, France ; 4 Hunan Univ., China)

An analysis of NAFTA'S economic relations: emphasis on energy commodities
E. Vitor, R. Bone (Univ. Federal do Rio de Janeiro, Brazil)

Questions and discussion

18:30 ***End of the presentations*** *– Departure to the cocktail party*
Short walk to Café Leffe, 2 Passage d'Arcole, Rueil-Malmaison

18:45 ***Cocktail party at Café Leffe***

Tuesday 19 June

9:00 *Registration and welcome coffee*

9:30-12:00 SESSION 4: ENERGY ECONOMICS METHODOLOGY

Chaired by Ramteen Sioshansi (The Ohio State Univ.)

Keynote: Understanding the future of natural gas infrastructure
S. Siddiqui (Johns Hopkins Univ., USA)

Coffee break

Reciprocal dumping by locally regulated monopolists
S. Debia, G. Zaccour (HEC Montréal–GERAD, Canada)

Second-best pricing when markets are incomplete
N. Astier (French energy regulatory commission, Toulouse School of Economics, France)

The marginal cost of demand response in a stochastic environment
A. Verrier (Chaire European Electricity Markets, Univ. Paris-Dauphine, France)

Questions and discussion

12:00 *Lunch*

13:20-15:00 SESSION 5: GAS ISSUES

Chaired by Olivier Massol (IFPEN)

The option value of GAZPROM's spare capacity under threat of US LNG on european gas market
S. Boussena, O. Ionescu, C. Locatelli (UGA, Grenoble INP, CNRS, GAEL, France)

Identifying inefficiencies in an Entry-Exit gas system
F. Perrotton (IFPEN, EconomiX, Univ. Paris Nanterre, France)

The economics of daily natural gas demand in France and in the UK
A .Thomas[1,2], O. Massol[3], B. Sévi[2] (1 IFPEN, 2 LEMNA Nantes Univ., IFP School, France)

Gas and LNG markets: are we facing a globally integrated market?
E. Dukhanina[1], O. Massol[2] (1 Mines ParisTech, 2 IFP School, France)

Questions and discussion

15:00 *Coffee break*

15:30-16:50 SESSION 6: ELECTRICITY MARKETS

Chaired by Sébastien Lepaul (EDF)

Analysis of a regulation on energy storage investment: the example of the new system operation guideline impact in terms of battery sizing for provision of frequency containment reserve
A. Rossé, T. Hinchliffe, J. Pierre, K. Lascar, M. Steward (EDF, France)

Modelling and value of storage for arbitrage and peak capacity in a high renewable european power system
A. Grandjean, T. Hinchliffe, P. Fourment, P. Verwiebe, V. Silva (EDF R&D, France)

Pareto-efficiency curves for designing cost-efficient energy policies on the electricity sector
M. Villavicencio (Chaire European Electricity Markets, LEDa – CGEMP, Univ.Paris-Dauphine, France)

Questions and discussion

16:50 ***Closing address*** *by the Organization Committee*
E. Hache, B. Chèze (IFPEN), O. Massol (IFP School)

17:00 *End of the conference*

ABSTRACTS OF THE ORAL PRESENTATIONS

Abstracts are listed following the order of the program

The abstracts are published in their original format, i.e. the format in which they were sent to the Scientific Committee.

THE SUPPLY OF ENERGY SERVICES : DO LOCAL SERVICE PROVIDERS USE DSO OR TELECOMMUNICATIONS NETWORK?

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Overview

The deployment of smart technologies in energy sector and environmental or energy policy goals have increase the role of information needed to deliver energy services to end users. However, electricity firms need to overpass uncertainty linked to new business models, expected regulations and potential entrants, which are some factors from all those that inhibit the smart grid transition (Shomali and Pinkse, 2016). Namely, Local Service Providers (LSPs) could offer several energy services to inform consumers and to help them improve their overall energy efficiency. These services could be of a wide range, using sensors to manage consumption of appliances. Relying on energy boxes or smart meters, they could use different kind of user interface to display consumers' energy data, such as an in home display or an Internet platform. To provide these services and thus manage a bidirectional transfer of data, LSPs could use mainly two networks. The first one is the Distribution System Operator (DSO) network, wich could be used to send signals or informations to consumers, through for instance any in home display connected to the smart meter. They also could use the household electricity network with smart meters to receive some informations on consumption or directly manage some appliances, as it is currently done for water-heater under time of use tariffs. As the business of the DSO is regulated, LSPs should pay a regulated access fee to use the electricity network. Beside the DSO network, LSPs could also use the "classic" telecommunication network, using for instance an energy box connected to the consumers' Internet access. In this case, LSPs do not contract with the DSO but directly with consumers : on the one hand to provide the expected energy services and on the other hand to use a defined bandwith of their Internet access. In that case, LSPs could have to compensate consumers for that bandwith. If not, LSPs could directly contract with Internet Service Providers (ISPs) to use a defined bandwith at a negociated price, the Internet sector being competitive. Two effects could be observed following this negociation. The first one is that the Internet access price could drive the supply of energy services if the two networks are not substitute. Thus, ISPs market power impacts the LSPs activity on the energy sector. The second one is that if LSPs widely use the Internet network, ISPs must invest and develop it to make sure energy services could be served. Then, ISPs must recover their additional investment costs (Heidell and Ware, 2010).

Methods

We use a Hotelling model to study the choice for two LSPs between two networks to serve consumers (Kitahara and Matsumura, 2013). We assume the two LSPs are in competition on the energy service market (the downstream market). Each of them maximizes its profit on the downstream market. They could use DSO's network or ISPs' network to provide their energy services. Thereafter, the use of DSO's network comes at a regulated price, whereas it comes at a negociated price for ISPs network. If they choose the DSO's network, they pay an access fee which is set by the regulator as maximizing the social welfare. Thus, the choice of a network to serve the demand relies on network costs, as a proxy of their efficiency, but also on the regulated access charge and the negociated price between ISPs and LSPs.

Results

We show that regulator could, when optimizing the social welfare, set the regulated access charge as a function of supply, network costs and consumers switching costs. Using the DSO's network could also reduce the weight of its fixed costs and thus could create further social welfare improvements. Allthough duplicating at least some fixed costs, the use of the two networks is allowed due to the existence of switching costs for consumers. Then, as the regulator could have incentives to increase the level of the access charge to optimize the social welfare, each LSP could use a network to serve consumers' demand in energy services. We also show that regulators of telecommunication and energy sectors could impact the competition on the downstream market of energy services. As in Fiocco and Scarpa (2011), in order to improve the social welfare, regulation authorities should coordinate themselves on the setting of the access charges and also regulate negociations rules between ISPs and LSPs.

Conclusions

The market of energy services is a great example of the co-existence of electricity and telecommunications networks often described in the context of smartgrid deployment. The choice of the DSO's network to provide energy services could increase the welfare as the access fee is regulated, as this network could be spread at a lower costs, and also as it could benefits from large increasing economies of scale. However, LSPs could prefer to use ISPs' networks to have a direct access to consumers with their own technologies, and also to enhance their independence from DSO's activities. Then, the contract with the ISPs could impact which consumers the LSPs could provide through this network, because of the existence of switching costs and of an efficiency gap between the two networks. If consumers are captive, LSPs could charge higher pricing policies using ISPs' networks without any significant decrease in demand. Overall, it could be welfare improving that LSPs use the same network, i,e the DSO's network to avoid additionnal duplication of costs. Obviously, if the regulated price is too high (meaning the DSO's network is way too inefficient), LSPs should prefer to use the ISPs' networks even if they are exposed to ISPs' strategies, such as market power or recovering new costly investments costs.

References

Fiocco R., Scarpa C., 2011, "The regulation of interdependent markets", working paper, SFB 649 Discussion paper, n°46.

Heidell J., Ware H., 2010, "Is there a case for broadband utility communications networks ? Valuing and pricing incremental communications capacity on electric utility Smart Grid networks", The Electricity Journal, vol. 23, n°1, p. 21-34.

Kitahara M., Matsumara T., 2013, "Mixed duopoly, Product Differentiation, and Competition", The Manchester School, Vol 81, Issue 5, pp. 730-744.

Shomali A., Pinkse J., 2016, "The consequences of smart grids for the business model of electricity firms", Journal of Cleaner Production, Vol 112, Issue 5, pp 3830—3841

IDENTIFYING ELECTRICITY DEMAND FOR RESIDENTIAL CONSUMERS: A SOCIAL, ECONOMIC AND TECHNICAL ANALYSIS AT THE LOCAL LEVEL

Mathieu Bordigoni, Thomas Verderi

Enedis, France

Keywords : Electricity demand, Residential customers, Econometrics, Cross-sectional, Local consumption

Overview

For all stakeholders involved in the electricity system, a clear understanding of consumption behaviours is essential to face new challenges related to the energy transition. Residential sector is a major contributor to overall electricity consumption. However, in order to establish relevant energy policies or investments planning, an evolving overview of the underlying causes of energy demand is often missing. With further electrification of mobility and heating, the design of a rapid and updateable estimation method is a major issue.

However, most current studies are based on costly and time-consuming surveys of households. Building a representative survey without sampling bias, at a national scale, may be a demanding task. In addition, such a methodological approach may not be appropriate to capture new 'weak signals', as the increase of electric vehicles, heat pumps or self-consumption of electricity. We suggest a new method to estimate drivers of residential electricity consumption, whether social, economic or technical, based on a cross-sectional semi-individual design analysis of local consumption.

Combining information on individual annual consumption of consumers with social, economic and technical data at the neighbourhood scale, it is possible to identify relationships between electrical demand and explaining variables as electrical heating, building age, household composition or social category. This analysis can be performed every year to follow trends in energy consumption, or energy efficiency. In addition, this approach may be adapted to target new energy demand behaviour with a substantial development in only few local areas, as PV production or electric vehicles.

Methods

The methodology proposed is based on the statistical analysis of two combined set of data established at a local scale (neighbourhood level):

- Distribution of individual annual electricity consumption for residential customers in the local area
- Aggregated information at the local level characterizing households
  - Incomes / Poverty
  - Composition of the population (age, household size)
  - Technical description of housing (type, size, building age, heating, secondary residence)
  - Socio-professional categories (executive, farmers, blue-collar workers…)
  - New electricity uses (electric vehicles, distributed generation)

Distribution of individual annual electricity consumption is divided in a variable number of quantiles for each local area. Then, a system of regression equations is defined; each quantile of annual consumption is explained by a common dataset of social and technical information at the local area. Regression equations are then estimated using variations in local conditions among thousands of areas at the national level, for a specific year. In that sense, we are using a cross-sectional analysis with a semi-individual design; measurement

level of outcome is individual and explaining variables are aggregated (Künzli N. & Tager IB., 1997).

A set of coefficients is then obtained for each explaining variable; one set for each quantile. Coefficients for a same variable may be significantly dissimilar for different quantiles of annual electricity consumption. For instance, the local proportion of secondary residences, with generally a low level of consumption, impact mainly low quantiles of local consumption, less higher quantiles. By differentiation, it is consequently possible to estimate the distribution of annual consumption for all residential consumers belonging to a specific group, e.g. the distribution of individual annual consumption for households with an electrical heating system or for those living below the poverty line.

The robustness of the proposed methodology is tested in two different ways:

- Comparison with existing surveys on residential customers demand.
- Uncertainty analysis of the semi-individual design with simulated consumption individual data.

Results

The proposed methodology has been applied to analyse electricity consumption of French households, in 2015, including about 45.000 local areas. The objective is first to test the proposed methodology using technical determinants with well-known effects on electricity consumption, as well as some social characteristics.

As a result, a distribution of individual annual electricity consumption is obtained for each group, with potential interactions between selected variables. For example, a national distribution of electricity consumption for two-room or one-room apartments with electrical heating, owned by an executive, may be estimated, as illustrated in the following figure:

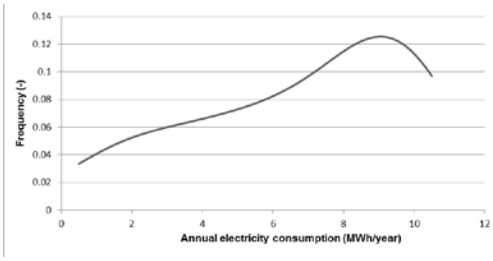

Figure 1: Estimation of the individual annual electricity consumption distribution for households living in two-room or one-room apartments with electrical heating, owned by an executive.

Conclusions

Understanding electricity consumption behaviours for different groups of residential consumers is essential for energy policy and investments planning, as residential consumers may have a very heterogeneous demand. This can help to target incentives more accurately or to anticipate potential distributive effects. This is especially relevant for local decisions as some neighbourhoods or cities may have very different drivers of residential electricity consumption.

References

Künzli, N., Tager, T.B. (1997): “The Semi-individual Study in Air Pollution Epidemiology: A Valid Design Compared to Ecologic Studies”, *Environmental Health Perspectives*, 105(10):1078-1083.

Mathieu Bordigoni, Thomas Verderi, 34 place des Corolles, Identifying Electricity Demand for Residential Consumers: A social, economic and technical analysis at the local level, 01.81.97.53.93, mathieu.bordigoni@enedis.fr

ON THE VIABILITY OF ENERGY COMMUNITIES

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Keywords:
Energy communities, Cooperative game theory, Decentralized power production, Consumer participation

Extended abstract:

The notion of energy communities has received increased interest over the past few years, triggered by better information and communication technologies and an increase in environmental awareness. These communities are sometimes seen as a viable business model that will foster local production and consumption of renewable energy. However, despite the potential profits made by such communities, there is no guarantee that they will be viable as a subset of participants may find it profitable to exit the community and create another one of their own if not properly remunerated. Our main goal in this paper is to analyze some conditions under which an energy community will remain stable. We consider households of a common building or close geographical area that may decide to combine their effort in a community, and jointly build solar panels on their roofs (or windmills in a nearby field). We then consider two sources of potential gains: aggregation gains, in the form of decreased network fees, and energy gains, as the renewable energy can be consumed at zero marginal costs or re-injected in the network at a feed-in tariff. The challenge of the community is to find a proper, stable and fair (these notions are rigorously defined in the paper) way to share these benefits among its members. We treat this problem within the framework of cooperative game theory. An array of results is found, depending on the cost structure of renewable installations. We show that the most basic sharing rules (per-capita, pro-rata of consumption or peak demand) usually fail to provide adequate remuneration to all players. In that case, some households may decide to opt out from the community. They may then try to create another smaller community with other unsatisfied households or may remain on their own. We find that diversified households with different generations, family size, occupation status, under the same roof create more value, and are therefore more likely to stick together as a community. More elaborate sharing rules, such as the Shapley value or the minimum variance allocation, though slightly more complex, have desirable properties and are more likely to enable communities to share their gains, thereby enabling them to be viable. When the community cannot be stable, the intervention of a social planner or a change in network tariffs may be required to restore efficiency. If such an intervention is not desired, we propose a way to optimally split the whole energy community into smaller stable groups of consumers, so that the lost value when splitting is minimized. At this stage of our research, we will restrain ourselves to only assessing the game-theoretical implications of communities, inasmuch as they are motivated by financial incentives. Noneconomic motivations, as well as potential externalities will not be explicitly modelled. The present paper is related to at least two strands of the literature. The first pertains to the literature on cooperative games. Clear expositions of how cooperative game theory can be applied to costs and surplus sharing in many sectors can be found in Young (1994), Moulin and Shenker (2001) and Moulin (2002). These elements have been applied to a wide variety of topics in the energy sector (Massol and Tchung-Ming 2010; Hagspiel, 2016, etc.). The second is related to the literature on decentralized energy systems. Substantial applied research has been done on decentralized generation, from an engineering or optimization perspective.

For example, Ahn https://www.gov.uk/government/publications/gas-securityof-supply-strategic-assessment-and-review (2013) and Kraning (2013) provide insights into the optimal dispatch of decentralized generation. Likewise, operational research on energy communities and micro-grids has also been very active recently, showing an increased interest in these business models (Olivares et al. (2014), Basak et al. (2012), Steinheimer et al. (2012), etc.), of which the benefits have been widely stressed, both theoretically and empirically. All of the previously mentioned papers envisage rather sophisticated energy communities endowed with technologies such as storage or demand-response. In contrast, we do not explicitly model these aspects so as to focus on the issue of gain sharing within the community. Indeed, the literature has so far restricted the analysis to the technically achievable benefits yielded by such communities, while very little research has been made to date on the actual viability of the community seen as a coalition. We believe that our study is the first to apply cooperative game theory within energy communities as such, which is our main contribution. The other important contribution of this work is to propose an optimal stable partitioning as a way to treat the instability of the energy community. Each sub-group might then create a smaller viable community on its own.

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THE URBAN MINING AS A SOLUTION FOR THE SUPPLY OF CRITICAL MINERALS

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PhD : The supply politics of critical mineral : the analysis of the value chain of lithium and cobalt in lithium energy storage systems

Keywords: Critical minerals, Security of supply, value chain, urban mine, material flow analysis

In September 2010, China put an embargo on rare earths at destination to Japan, transposing the diplomatic issue about the Senkhaku Islands into commercial retaliations with vital implications. Rare earths are indeed essential to the Japanese industry as they are used to produce the magnets for PHEV vehicles or wind turbines.

More globally, western countries became aware of their vulnerability regarding the supplies of so-called critical mineral essential for their economies. Several initiatives taken by Japan (JOGMEC, 2005), USA (USGS, 2018) and the European Union (EC, 2011) allowed to identify the cause of tensions. First is their growing consumption for the manufacturing of products, vital for the security of a country or for the implementation of energetic transition policies. Second, is the availability of these minerals for which the production capacities did not follow the demand. Third issue, the progressive withdrawal from their production by the western countries at the advantage of China. As an example, China produces more than 50% of 16 of the 27 critical materials listed by the EU, including 95% of rare earths and 87% of magnesium (EC, 2017).

However, the Chinese rising involvement in critical minerals not only concerns the production but also refining and final use. China produces only 3% of the cobalt mineral but 60% of refined cobalt. (Darton commodities, 2018). It also uses more than 60% of the global production of cobalt for its own needs (Roskill, 2016). The positioning of China on the value chain of critical minerals has evolved since the years seventies. The Chinese production became more value added, from the production of minerals to the use of the metals through the refining process (Piteron, 2017).

Nonetheless, initiatives taken by western countries to identify their vulnerabilities led to the development of corrective strategies. In addition to the calculation of the criticality through algorithms, the Raw Material Initiative (RMI, 2011) added three pillars to its strategy: the sustainable production of minerals within the EU, the supply of the EU and an efficient use of the resources notably through the secondary production (EC, 2011).

Studies on the value chain of critical minerals in the EU reveal the presence of several stakeholders on the segment of production (Boliden (SW), Eramet (FR)…) and of refining (Umicore (BE), Aurubis (GER)…). Therefore, increasing capacities in production and

refining may certainly be attainable but requires European industry to compete with the Chinese prices. In addition, mining activities in Europe suffer a negative image in the population, which slows the development of mining projects.

The development of a proper production of critical minerals may lay not in the production of primary resources but rather of secondary ones. The EU sits indeed on a formidable deposit called the urban mine, formed notably of IT, electronic and household electrical products, where critical minerals are present in very small quantities. As an example, the concentration of gold and silver in one ton of Printed Computer Boards is 100 times higher than in the best mines (Chancerel, 2008).

In the framework of its third pillar, the EU stimulated the research and development of recycling technologies (Oko-institut, 2013). Even if the question of recycling is linked to the profitability of the processes, a first step in this direction requires a knowledge of material flows in the economy. The method called Material Flow Analysis (MFA), may give the opportunity to anticipate the flow of end-of-life products and the quantities of metal they contain and so, anticipate the necessary investment in the infrastructures to treat the products and recover the materials (RMSA, 2015).

Illustrated by the case of cobalt, the present proposition aims to show that the production of critical minerals in Europe is possible at three conditions. The value chain of cobalt is not limited to the production of primary materials and the EU should encourage the production of secondary resources through the exploitation of the urban mine. This requires a good knowledge of the cobalt flows in circulation in the EU under the form of material or products, in order to anticipate the quantity of resources recoverable for the coming years. Finally, as such initiatives would partly allow the supply of vital resources for the EU, it might be interesting to study them not only under a profitability scope but also under a security scope.

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DOES LITHIUM REALLY MATTER FOR THE ELECTRIFICATION OF THE TRANSPORTATION SECTOR?

Dr Emmanuel HACHE, Dr Gondia Sokhna SECK, Marine SIMOEN, Dr Clément BONNET

IFP Energies nouvelles

Keywords:
World transport, electrification, critical raw materials, lithium, Bottom-up modelling

Abstract

To ensure the compliance with stringent climate goals and to improve energy security, different countries are willing to step up their efforts to accelerate the development and deployment of electrification of transport. In that context, new and unexpected interdependencies, such as dependencies to critical materials and more especially to Lithium, could be observed. Indeed if historically lithium is used in the glass and ceramic industries, with the development of Li-ion technologies, lithium also found a strong new market in the battery sector for small electronics (phone or laptop in particular) and is also now driven by electric vehicle (EV). Today the size of the lithium market is not very large compared to non-ferrous metal (copper, nickel, lead, etc.), poorly organized and not very transparent regarding its price formation. From an industrial organization point of view, the concentration of reserves in a small number of countries (the lithium's triangle in South America) and the oligopolistic structure of the industrial players (mainly Chinese and Americans companies such as Albermale, FMC, SQM and Tianqi Lithium which represent around 78% of the market share for primary lithium) make market development very uncertain. In that context the purpose of this article is to assess if accessible lithium resources are sufficient for expanded demand due to lithium battery EV worldwide and what does the future hold for lithium geopolitics. We rely on our linear programming World Energy-Transport model based on the ETSAP-TIAM model (Times Integrated Assessment Model. ETSAP-TIAM) to compute a partial equilibrium. The model covers 16 regions with a time horizon up to 2050. It is used to conduct a systematic examination of potential futures of the transport sector under two climatic scenarios 2°C and 4°C. We modeled lithium supply chain at the world level to study market dynamics over a multi-period time horizon. Our work tend to show that a marked penetration of the electric vehicle worldwide should not lead to a shortage of lithium, even in the scenario converging towards 2 ° C by 2050. However, long-term equilibrium commodity markets teach us that the lack of objective criticality of resources does not avoid different forms of vulnerabilities, which should be found in economic, industrial, geopolitical or environmental fields. The main risks concerning the lithium market are based on the evolution of the structure of its market and more especially the concentration of the main players. Price volatility could weaken newcomers on the market and lead to new consolidations (mergers and acquisitions) between the players and a market power in the lithium market. National production strategies are also an extremely important risk parameter for the lithium market in the coming years. We will discuss all these different aspects to conclude on future lithium market vulnerabilities.

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MARKET OR NOT MARKET? ENSURING RARE EARTH SECURITY OF SUPPLY FOR THE DEFENSE SECTOR

PALLE Angélique

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Keywords : Rare earth, defence, security of supply, policy

Rare earths have become a key element for many military and dual technologies. From standard communication means to missile guidance or key structural aspects of very specific equipment like the US F-35 aircraft, they pervade, in very small quantities, most of the technologies used today in the defence sector.

China is currently the principal producer of rare earths and price maker on a strategic but quite small market (140 000 tons produced each year for a value that does not exceed 13 billion of USD). Its strategy over the last decades has been, in a context of global expected and ascertained demand growth linked to both the energy and digital transitions, to progressively gain control of the entire value chain. Working its way up from production (97% of exported rare earth oxides) to components (60% and 75% of the two most used magnets containing rare earth elements) and alloys (90% of world production) manufacturing, and more recently the new generation of patents. This strategy and the supply crisis that occurred in 2010 over a diplomatic incident between China and Japan have led Japan, the US and the EU to rethink their security of supply, initially entrusted to the market, for the upcoming decades.

This presentation is an assessment of these strategies and their efficiency from the defence point of view. In most cases, the 2010 crisis has led the armies to try to assess their exposure to rare earths supply shortage. The inventory of what is exactly used, where it comes from and in which equipment it is present has proven difficult if not impossible.

Two different reactions can be identified so far. The US have played the market card and focused on the bottom of the supply chain. They have let Magnequench, subsidiary of General Motors which owned some of the major patents in the sector, to be bought by Chinese funds. After the 2010 crisis they focused on the reopening of their mine of Mountain Pass which couldn’t face the market conditions (and the low prices) and filed for bankruptcy in 2015, before being bought in 2017 by a Chinese-led consortium.

Japan on the other hand targeted the other end of the supply and value chain. The country is focusing on acquiring the new generation of patents and developing recycling technologies. Japan is also both investing in and supporting the development of other sources of production and supply, outside of China.

The Chinese reaction has been plural and includes: 1.the constitution of stocks, the amount of which is yet unknown; 2. the maintenance of low prices for rare earths on the market which prevents the emergence of other market players; 3. investment in all the ongoing projects (Greenland, India etc.); 4. a (more or less willing) environmental and social dumping on the extraction of rare earth ore that had led most of the western countries to initially accept the progressive Chinese domination on ore extraction.

Given these different aspects and the high capital costs of the development of new mines (between 100 million and 1.5 billion of US dollars for the opening of a new mine, for a market that currently doesn’t exceed 13 billion of US dollars per year) it is currently impossible to rely on the market for the apparition of new competitors which would guarantee a diversity of supply and put an end to China’s market and geopolitical power.

The EU has also started working on the evolution of the rare earth markets, having in mind the needs for both its energy transition and its defence sector. It has produced so far, either at the European or the member states level, a series of criticality analysis and an assessment of the European reserves and industrial capabilities but hasn't come up with a strategy to ensure the security of supply. Do we define one "outside" of the market? Strategic stockpile, recycling or on-site production and manufacturing all come in with different costs (whether economic, environmental or social) and the choice remains political.

Bibliography

Bailey Grasso, V., 2013, *Rare earth Elements in National Defense: Background, Oversight Issues, and Options for Congress*, US Congressional Research Service.

Barteková E. and Kemp R., 2016, "National strategies for securing a stable supply of rare earths in different world regions", *Resources Policy*, 49.

BRGM, *Panorama 2014 du marché des Terres Rares*, Rapport BRGM/RP-65330, Novembre 2015.

Chinese Ministry of Industry and Information Technologies (MIIT), 2012 Situation and Policies of China's Rare Earth Industry, MIIT White paper.

European institute for Asian studies, Europe's Rare Earth Dependence on China: Future Perspective, EIAS Briefing Paper 2014, 7, December 2014.

Japan's Ministry of Economy, Industry and Commerce, "Termination of China's Export Duties on Three Raw Materials Including Rare Earths", 2015.

Mancheri Nabeel.A et Marukawa Tomoo, "Rare Earth Elements, China and Japan in Industry, Trade and Value Chain", *ISS Contemporary Chinese Research Series*,17, March 2016.

Paulick H. and Machacek E., "The Global Rare Earth Element Exploration Boom: an Analysis of Resources Outside of China and Discussion of Development Perspectives", *Resources Policy*, 52, 2017.

Wübbeke Jost, "Rare Earth Elements in China: Policies and Narratives of Reinventing an Industry", *Resource Policy*, 38, 2013.

Schlinkert D. and Van den Boogart K. G., "The Development of the Market for Rare Earth Elements: Insight from Economic Theory", *Resource policy*, 2015.

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COPPER AT THE CROSSROADS: ASSESSING THE IMPACT OF AN OLD AND ESSENTIAL METAL ON THE ENERGY TRANSITION

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Keywords: Energy transition, copper, transport, electrification, Bottom-up modeling

Copper in the energy transition context

The aim of this article is to assess the impact of copper availability on the energy transition and to answer the question whether or not copper might become critical due to the high copper content of low-carbon technologies of the electricity and the transport sectors. To answer this questions we use a bottom-up model in which the copper supply sector is represented. Before detailing how the supply sector is modelled, we insist on the essential links between low-carbon technologies and copper availability. Due to its physical properties and to its numerous applications, the consumption of copper has significantly increased since the beginning of the 1960s. Because low-carbon technologies have higher copper contents compared to conventional technologies, we can expect the energy transition toward a low-carbon system to contribute to increase further the demand for copper. In this article we conduct a prospective analysis of the evolution of the electricity and the transport sectors. As these sectors are major greenhouse gas emitters, it is a crucial question to understand if copper availability can constitute a brake to the deployment of low carbon technologies. For instance, we have computed that building-mounted solar PV installations have a copper content that is 5 to 7 times higher than a lignite coal power plant with the same capacity.

Risk factors of a bottleneck in the production of copper.

Based on preliminary analyses, we have identified several risks of a future bottleneck on the supply of copper. First, the copper reserves are depleted and most of major producer countries have enough copper reserves to sustain their 2015 production levels of copper for less than four decades. Second, we can expect the cost of producing copper to increase over time due to declining ore grade. Third, copper recycling have a limited potential over the next decades due to both the immobilisation of vast amounts of copper in long-lived products and the low actual recycling rates in short-lived products. Four, the historical trends reflect a growing concentration of the refining sector as China became the bigger producer of refined copper. Taken into account the high market power of China on the copper market and the growing Chinese domestic consumption, we can fear a decrease of copper availability.

Research strategy.

A representation of the copper supply sector is implemented in the ETSAP-TIAM model (Times Integrated Assessment Model). It is the global multiregional version of the TIMES (The Integrated MARKAL-EFOM System) model generator. The objective of the model is to

minimize the cost of the (energy) system under several climatic scenarios. As the model covers several regions of the world, we are able to assess the energy and copper market dynamics over a multi-period time horizon.

Results and discussion.

Several scenarios are simulated and a careful examination of the results is conducted. We assess to what extent the higher copper-content of low carbon technologies constitutes a barrier to their large scale deployment. We then discuss the notion of criticality and assess if copper can be expected to become a critical metal. A geopolitical analysis is also carried out on the basis of the evolution of the trade structure of copper.

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ALLOCATING PROVINCIAL CO_2 QUOTAS FOR THE CHINESE NATIONAL CARBON PROGRAM

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Keywords: CO_2 quota allocation; Chinese national carbon program; marginal abatement cost; interprovincial differences

Abstract

To deal with climate change at the lowest cost, China formally launched on December 19, 2017, its national carbon market, in which the initial CO2 quota allocation is one of the key issues. How should we allocate CO2 emissions reduction responsibilities among Chinese provinces, assuming that provinces will not or cannot trade these responsibilities amongst themselves? In this paper, we allocate CO2 quota from the perspective of cost minimization. First, we estimate the national CO2 marginal abatement cost (MAC) function and deduce the interprovincial MAC functions. Second, we build an allocation model with the nonlinear programming approach for cost minimization. Finally, we obtain the allocation results under the emissions reduction target by 2030. The results are as follows. (i) The national MAC was 134.3 Yuan/t (at the constant price of 1978) in 2011, with an overall upward trend from 1990 to 2011. (ii) The interprovincial MACs differ significantly and decline gradually from east to west. Hebei has the largest emissions reduction quota and Shandong has the largest emissions quota by 2030. (iii) Compared with other criteria of per capita, gross domestic product (GDP), grandfathering, and carbon intensity, the proposed approach is the most cost-effective in achieving the reduction target, with cost savings of 37.7%, 34.5%, 47.9%, and 33.87%, respectively.

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AN ANALYSIS OF NAFTA'S ECONOMIC RELATIONS: EMPHASIS ON ENERGY COMMODITIES

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The globalization trends established in the post-World War II period fostered the emergence of trading blocs and free trade zones. In this context, the NAFTA stands out as the most important free trade agreement worldwide, which has the United States, Canada, and Mexico as members. The socioeconomic gaps between the NAFTA members and their respective importance in the energy scenario are both the motivation and starting point of this work, which aims to analyse the relationship between economic variables within NAFTA as well as conceive if there is an energetic self-sufficiency in North America based on its energy commodities trade.

It is well known that the American economy is responsible to drive the international patterns and it is broadly synchronized with the global cycles, a phenomenon called "contagious effect". Canada, for its turn, has high socioeconomic indexes and it is endowed with a diversified energy portfolio that has been actively contributing to its economic growth. The country is currently adjusting its economy to the changes in oil prices, which had increased the unemployment rate in oil provinces. Mexico, on the other hand, has been going through a series of structural reforms that, in an energetic framework, aims the openness of the sector to foreign investments participation in exploration and production (E&P), which was not allowed during the state-owned *Petroleos Mexicanos* (PEMEX) monopoly; hence contributing to a rough decline in production and refinery outputs.

In this way, an analysis of the macroeconomic potential of the three countries was carried out based on variables such as annual GDP growth, trade balance, unemployment rate and inflation rate. An evaluation of energy commodities (oil, natural gas, and coal) trade flows was performed in order to assess the main energy trading partners of the three countries, evincing the tight integration between the United States and Canada, mainly when it comes to the natural gas market.

Additionally, the work analyses the trading flows of US crude oil and refined products since the NAFTA's implementation in 1994 in order to evaluate Canada and Mexico's contributions in American oil imports and exports as well as the dependency of external players such as OPEC-members. The Pearson Correlation was used to evaluate the degree of correlation between the economic variables studied according to the qualitative criteria to be described. Also, a correlation between energy consumption and CO_2 emissions was considered due to its influence on policy-making, especially concerning the ongoing debate about climate change.

The conformity between obtained and expected results was greater for the United States and NAFTA. It suggests that the United States plays a key role regarding North America economic indexes, as initially expected. Besides, the correlations between a) GDP growth and energy consumption and b) energy consumption and trade balance were the most representative. In summary, the global analysis of trade flows led us to conclude that NAFTA has been amplifying the commercial relations amongst its members whilst reducing them with external countries even though this trend seems to be gradual.

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RECIPROCAL DUMPING BY LOCALLY REGULATED MONOPOLISTS*

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Abstract

Countries' competition structure and policy impacts trade efficiency, but it is not within WTO's jurisdiction to monitor them, as long as they are not discriminatory. This paper develops an international-trade game with two local monopolies regulated by a non-discriminatory competition policy. They may freely export but have to sell in their local market at a price equal to their marginal cost. We consider a two-stage setting where local production is decided after exports. We characterize sufficient conditions for existence and uniqueness of the subgame perfect Nash equilibrium in two scenarios, namely, without and with local regulation. If the two countries are sufficiently similar, trade may destroy value rather than creating it, for each representative agent in the economy. This effect is mainly due to an increase in dumping incentives due to local regulation. These results are counter-telling the traditional viewpoint that price-making behavior is a necessary condition for dumping in a deterministic framework.

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SECOND-BEST PRICING WHEN MARKETS ARE INCOMPLETE

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Keywords
Incomplete markets, second-best, policy evaluation

Abstract
Although the canonical Arrow-Debreu model indexes commodities by their location, date and contingency of delivery, goods traded in actual markets are never completely differentiated along all these dimensions either for technical of political reasons. For example, the ICT infrastructure needed to measure the traded quantities of every single Arrow-Debreu commodity may prove too costly to roll-out, or various constraints may not allow to differentiate prices across a subset of commodities.

This situation typically arises in the electricity and natural gaz industries, where the full commodity set in the Arrow-Debreu sense is huge and where the use of a common physical unit (kWh, cubic meter, Btu, etc.) makes the underlying economics fundamentals less salient than in markets for goods whose physical nature differs. Indeed meters sometimes can only measure aggregate consumptions over a fixed number of different periods, and retailers and/ or public authorities often prefer to implement simple tariffs relying on a limited number of parameters.

This paper develops a simple framework to design second-best tariffs when markets are incomplete, that is when, either for technical or political reasons, a market cannot be opened for each single Arrow-Debreu commodity. Such a problem is commonly encountered by numerous agents: retail or grid tariffs' designers, stock exchanges' product designers, etc.

In particular, our framework allows to estimate the opportunity cost of markets' incompleteness. This information may prove helpful to asses the benefits that may be achieved through R&D and technical upgrades (e.g. to improve the ICT infrastructure) or through political action to relax a given constraint.

As an example of numerical application, we show how our framework may be used to compare the potential benefits of Critical-Peak Pricing versus Time-of-Use for electricity retail tariffs in France.

Finally, we discuss the potential interactions between second-best pricing and long-term investment incentives.

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THE MARGINAL COST OF DEMAND RESPONSE IN A STOCHASTIC ENVIRONMENT

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Keywords: Demand Response; SDDP; Marginal Cost; Electricity markets.

Context

Integration of Demand Response (DR) in power systems is determined by electricity consumers' willingness to participate in a DR programme. If the financial reward given to consumers is key to foster participation, the number of DR activations allowed over a given time period (often called frequency) also plays an essential role, since consumers might not have the technical ability to deal with DR events occurring on a too regular basis. Consumers may thus accept to participate against a limited number of DR activations, defining thereof an opportunity cost to trigger the DR event.

Framework

Our framework consists in a competitive energy-only market modelled by an economic dispatch under uncertainty. The model, featuring several time periods, is formulated as a cost-minimising multistage problem. It is solved by using the stochastic dual dynamic programming (SDDP) algorithm. On this market, a DR aggregator owns DR technologies that he can dispatch given market prices uncertainty and the frequency constraint. Frequency defines a limited amount of energy at the aggregator disposal, which can be seen as a storage that the aggregator has to optimally manage over the time horizon of the problem. In this multistage setting, his bidding decision thus takes into account the future cost function associated to the current decision of providing one MWh from the DR storage to the market.

Contribution and results

This paper suggests that the marginal cost of DR is made of the financial reward and the opportunity cost. The opportunity cost is derived from the future cost function built by SDDP. The opportunity cost is a decreasing function of the DR storage level. For low storage levels, the marginal cost can rise significantly.

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THE OPTION VALUE OF GAZPROM'S SPARE CAPACITY UNDER THREAT OF US LNG ON EUROPEAN GAS MARKET

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Keywords: real options games, European gas markets, Russian gas strategy, gas prices, spare capacity

Abstract

As part of its policy to establish a single, competitive market for gas, one of the priorities for the European Union is to diversify its sources of supply, in the face of the oligopoly formed by Russia, Algeria, Norway and Qatar. Under these conditions, the prospect of massive US LNG exports from shale gas development is challenging the strategy of the EU's incumbent suppliers. The structural and cyclical developments of this market - competitive market, excess supply (overcapacity of liquefaction), weak demand - have already led incumbent suppliers to adapt to maintain their market share.

The present article seeks to determine how US gas exports to Europe might change the behaviour of major incumbents and the strategic options open to them. The Russian gas company Gazprom may serve as a baseline for our analysis. With a 30% share of the EU gas market, it is a major supplier, exerting an influence on prices and enjoying several comparative advantages (Boussena and Locatelli, 2016). US LNG exports could thus compete strongly with Gazprom in the North-West Europe market, the heart of the Russian company's strategy. On the latter, Gazprom is a major player, but it is not a "price maker", especially since most of its sales (nearly 80%) are made in the form of long-term contracts (TOP), with a price indexation formula based on those of oil. Today, the major challenge for Gazprom lays not so much in current US LNG exports as in future projects because of the resulting export volumes. This new conjuncture is forcing Gazprom to review its strategy. For the time being, with an over-supply market, the latter have simply adapted passively, mainly by revising some clauses of the long-term contracts which govern sales to the EU and more particularly by decreasing its prices (due to its low production costs, one of the main comparative advantages). However with the threat of growing competition, such strategy may not be enough to cope with the scale of US LNG exports.

Therefore, Gazprom's strategic behaviour, in the image of Saudi Arabia in the oil market, could be to define a strategy of uncertainty about future market conditions. To this end, Gazprom has a second comparative advantage, which is that of its unused delivery capacity (in terms of production and transport). With a significant *spare capacity* (150 Bcm) since the beginning of 2010 and in the specific context of the European gas market - hybrid, in overcapacity and not totally globalized - , Gazprom is able to influence the evolution of prices by using it or not on the spot markets. Likewise, the spare capacity may be a strategic variable that will strengthen the context of uncertainty in which decisions concerning new LNG projects are made.

Seminal theoretical contributions (Spence (1977) and Dixit (1980)) have attempted to take into account the excess capacity and its role in competition among firms. In recent years, real-options literature (Smets (1991), Dixit and Pindyck (1994), Grenadier (1996, 1999), Boyer, Lasserre, Mariotti and Moreaux (2002, 2012), Huisman and Kort (2015)) has concentrated on the effect of uncertainty on competition and interaction between firms in a market.

With a real options games framework, we analyse the effectiveness of using the spare capacity to modify the investment decisions of a possible new entrant. We derive the optimal entry and exit thresholds, the equilibrium strategies and the option value of Gazprom's unused capacity. More specifically, we extend previous contributions through a dynamic framework where the main player has the option to use or not the spare capacity which comes with zero cost and by focusing on the value of this option and its determinants: scale of supply, production cost advantage, price elasticity, volatility and growth rate. Under the threat of a new entrant, the incumbent may adjust its volume of sales, by injecting some part of its surplus capacity into the spot market or alternatively, holding back part of its available capacity. This unusual flexibility may alter the market conditions and thus the uncertain evolution of gas prices determined by an inverse demand function.

One of the main results of our model is that the incumbent's option to use or not the spare capacity at any time can afford protection for a while, discouraging a potential new entrant. However, the use of spare capacity to permanently prevent arrival of a new entrant is not sufficient, in the sense that it is possible to delay entry but not to forbidden it. Given the greater uncertainty on market conditions, the optimal behaviour for an entrant would be to wait long enough for prices to reach a level justifying investment in the EU market. This level of prices may be altered through the incumbent's competitive advantage of holding an important amount spare capacity. If the level of prices is sufficiently high, the incumbent may inject additional capacity on the spot market in order to dissuade its competitor. Likewise, we show that the market equilibrium and trigger values change accordingly the scale of the incumbent's spare capacity used on the spot market.

By giving a positive role to the opportunity to use the spare capacity as a strategic variable under threat of a potential competitor, our article has an important practical contribution as it allows the incumbent to choose the optimal timeline and scale in order to deter entry and maximize its revenues.

References

BOUSSENA S. et LOCATELLI C. [2016], "Guerre des prix ou instrumentalisation de l'incertitude sur les prix : Quelle stratégie pour un fournisseur dominant sur le marché gazier européen ?", Cahier de recherche EDDEN, 1/2016.

BOYER M., LASSERRE P., MARIOTTI T. et MOREAUX M. [2002], "Preemption and Rent Dissipation under Bertrand Competition", International Journal of Industrial Organization.

DIXIT A.K. et PINDYCK R.S. [1994], "Investment under Uncertainty", Princeton University Press, Princeton, NJ.

DIXIT A.K. [1980], "The Role of Investment in Entry-Deterrence", The Economic Journal,Vol. 90, No. 357, p. 95-106.

GRENADIER S. [1996], "The Strategic Exercise of Options: Development Cascades and Overbuilding in Real Estate Markets", Journal of Finance, 51 (5), 1653-1680.

GRENADIER S. [1999], "Information Revelation Through Option Exercise", Review of Financial Studies, 12 (1), p. 95-130.

HUISMAN K. et KORT P. [2015], "Strategic capacity investment under uncertainty", The RAND Journal of Economics 46, (2), p. 376-408.

SMETS F. [1991], "Exporting versus FDI. The effect of uncertainty, irreversibilities and strategic interactions", WP, Yale University

SPENCE A. M [1977], "Entry, Capacity, Investment and Oligopolistic Pricing", The Bell Journal of Economics, Vol. 8, No. 2, p. 534-544

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IDENTIFYING INEFFICIENCIES IN AN ENTRY-EXIT GAS SYSTEM

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Keywords: Entry-Exit, Network Tariffs, Gas Transport Network, Gas Target Model

The European Entry-Exit gas system regulates access to the gas transport network and organizes the commodity market. To do so, it separates gas trading from physical gas flows. While this fosters the liquidity of gas markets, it prevents from efficiently using the gas network.

We present a bilevel model of a single-zone Entry-Exit gas system where a network operator sets tariffs and capacity limits and anticipates the economic decisions of gas shippers. We compare it to the dispatch of an integrated utility and provide analytical and numerical results to document the sources and magnitudes of possible inefficiencies. So as to account for the technical constraints of gas networks, both models feature a simplified stationary gas flow model, adapted to their economic formulation.

We show that an Entry-Exit system is inefficient as soon as tariffs and capacity limits are set identically for more than two different demand instances. The enforcement of cost-reflective tariffs further hampers this prospect. Finally, we highlight that the choice of capacity limits based on technical grounds instead of economic ones is another distortion factor. Numerical results obtained on simple settings exhibit small inefficiencies, but also demonstrate the need to realize such case studies for existing Entry-Exit markets, where inefficiencies may be larger.

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THE ECONOMICS OF DAILY NATURAL GAS DEMAND IN FRANCE AND IN THE UK

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Keywords: Natural Gas; Daily Demand; Elasticities; Efficiency; Forecast.

Because of the rise of intermittent renewable energy sources of electricity, natural gas-based thermal generation is increasingly used as a back-up technology. The output of these thermal plants is highly variable and uncertain so is their consumption of natural gas. For natural gas infrastructure operators (TSO), this evolution adversely raises the cost to operate and balance the pipeline infrastructure as it imposes to increase the gas pressure within the pipeline system in order to maintain a suitable amount of "linepack". The application of efficient load forecasting techniques is expected to substantially lower that cost. Therefore, European regulators are increasingly requiring TSOs to improve the performance of their load forecasting techniques. In some countries (e.g., the UK), a dedicated incentive regulatory mechanism has even been implemented and a similar policy is currently examined in several countries (e.g., France).

Against this background, TSOs have begun to heavily invest in the development of modern forecasting tools. Though their work is not public, they are reputed to have implemented advanced nonlinear forecasting techniques which have provided substantial improvements. Yet, significant load forecasting errors still prevail.

Building on the seminal work of Forbes & Zampelli (2014), our approach to load forecasting begins by recognizing that the informational content of day-ahead prices. In case of efficient wholesale markets, it should thus be possible to model the quantity of natural gas demanded in a given day using two variables: the day-ahead price of natural gas (to model the reaction of both industrial users and households) and a spark ratio (i.e., the day-ahead price of electricity divided by the day-ahead price of natural gas) reflecting the economics of gas-based thermal generation.

The ambition of this paper is two-fold as it: (i) shows that the estimation of a simple specification can be sufficient to challenge the performance of the TSOs' forecasting models, and (ii) documents the short-run and long-run reaction of the daily consumption of natural gas to both the natural gas and electricity day-ahead prices by measuring the price elasticities.

We detail an application to the cases of major European gas markets: the two load balancing zones in France (North and South) and the 12 distribution zones that exist in the UK.

Methods

We consider the period covering 2014-2017 and assemble a data set comprising natural gas consumption data and daily transaction price data for day-ahead wholesale natural gas and wholesale electricity for peak periods traded during working days. As a learning-validation procedure will be used, our dataset is divided in two parts.

Our econometric methodology is based on the Autoregressive Distributed Lag (ARDL) modelling approach (Pesaran et al., 1997) and the associated bounds testing approach which is aimed at testing the long term relationship between the volume of natural gas

demanded and its drivers. The ARDL approach allows to treat the case where time series do not have the same properties of stationarity.

Results & Conclusions

Our results are five-fold. First we deal with model hypothesis on variables. All variables have different integration orders but in each country, they are at least I(1) that ensures ARDL estimation choiceinstead of VECM estimation.
Moreover that ensures the convergence of bound testing cointegration method.

Secondly, we check the endogeneity of the regressors in the model. Wu-Haussmann tests confirm non-endogeneity of day-a-head price and spark ratio that's the reason why we can use day-a-head price as regressor in each country to forecast the day-ahead load.

Third, in each case, we find that's a simple ARDL specification verify all the diagnostics tests, all tests about stability (CUSUM and CUSUM SQUARE), heteroscedasticity (ARCH test, Box-test) and autocorrelation (Box-test) are highly significant.

Fourth, the bound testing procedure reveals the existence of a long run relationship between the load and the day-ahead prices in each country and each zone. This findings allows us to contribute to the literature by providing for the first time, a measure of the price elasticity of the demand for natural gas which is derived from daily data.

Finally, we have compared the forecasting performance of our models to those of the TSOs. Our findins consistently indicates that our simple ARDL approach provides significantly improved forecasts. This is also the case in the UK despite the presence of an adapted incentive policy which is supposed to provide a strong incentive for the TSO to invest time and efforts into that issue.

References

Bernstein, R., Madlener, R., (2015). Short- and long-run electricity demand elasticities at the subsectoral level : a cointegration analysis for German manufacturing industries. Energy Economics.

Forbes, K., Zampelli, E., (2014).Do Day-Ahead Electricity Prices Reflects Economic Fundamentals? Evidence from the California ISO. The Energy Journal, 35(3).

Kofi Adom, P., Bekoe,W., (2012). Conditional dynamic forecast of electrical energy consumption requirements in Ghana by 2020: A comparison of ARDL and PAM. Energy.

Pesaran, M., Shin, Y., (1997), An Autoregressive Distributed Lag Modelling Approach to Cointegartion Analysis. Chapter 11 in Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium, Strom S (ed). Cambridge University Press: Cambridge.

Pesaran, M., Shin, Y., Smith, R., (2001). Bounds Testing Approaches to the Analysis of Level Relationships. Journal of Applied Econometrics, 16: 289-326.

The economics of daily natural gas demand in France and in the UK

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GAS AND LNG MARKETS : ARE WE FACING A GLOBALLY INTEGRATED MARKET?

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Market integration, Law of one price, Spatial arbitrage, Natural gas markets

Abstract

The goal of this paper is to examine the degree of integration between the spot markets for wholesale natural gas in different regions (i.e., Europe, North America, and Asia) provided their heterogeneity in terms of gas supply (e.g., markets interconnected via pipelines or liquefied natural gas). Taking into account that the degree of market integration impacts the strategic decisions for industrials and policy makers, it is important to determine the extent to which we can consider the global gas and LNG markets integrated. For doing this we analyze intermarket spatial arbitrage opportunities by employing a novel methodology based on spatial equilibrium theory. This theory suggests that on integrated markets the spatial price spread equals the intermarket transportation (arbitrage) costs, whatever the nature of the arbitrage (i.e., via pipeline or LNG). However, the costs, liquidity, and timing are not equal for pipeline and LNG transportation.

We conclude that the markets worldwide do not have the same degrees of integration, as estimated probabilities of the markets to be in spatial equilibrium vary between market pairs. This result means that it is too early to speak about a globally integrated gas market. Moreover, comparing the degrees of integration between the spot markets, we find some geographically distant markets to be more integrated than neighboring ones. This is observed through higher integration between European and Asian markets than between the markets within Europe. This result calls into question the common hypothesis that more closely located markets are more integrated. There are three potential explanations for this finding: (1) it may be caused by inefficiencies in some markets, (2) gas and LNG may not lie in the same economic market, or (3) gas and LNG may not be considered homogeneous commodities.

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ANALYSIS OF A REGULATION ON ENERGY STORAGE INVESTMENT: THE EXAMPLE OF THE NEW SO GUIDELINE IMPACT IN TERMS OF BATTERY SIZING FOR PROVISION OF FREQUENCY CONTAINMENT RESERVE

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Keywords

Regulation and Market Design, Investment, Power System Economics, Energy Infrastructures (Electricity Storage)

Abstract

The question of storage regulation is currently regularly discussed – while some examples of "mandates" and incentive regulations exist worldwide, the tendency in Europe, supported by the European Association for Energy Storage (EASE), is rather to promote a technology neutral approach, while being very careful to ensure a level-playing field (i.e. avoid the adoption of restrictive measures that might be proposed as battery storage is still a rather new asset in power systems).

Over the last years, one good example has been (and still is) the discussions at EU level regarding the rules for the participation of battery storage in Frequency Containment Reserves (FCR). Some very technical questions must be addressed (sizing, penetration rate, recharging strategies, etc.), as they have direct impacts on project costs, and thus on the amount of batteries that could be profitable on this market. Having very technical discussions at EU level has proven to be particularly challenging, and has often led to compromises in the definition of the rules.

With the evolution of electrical systems and network interconnections, the network codes and regulations must evolve in order to ensure the security and stability of electrical grids. Three operational network codes were recently merged into a new, single European network code: the System Operation Guideline (SOGL), which entered into force in August 2017.

SOGL defines specifications for FCR providers, with specific rules for units or groups with limited energy reservoirs (LER), for example, batteries. However, the specifications as specified today in the approved SOGL leave some aspects undefined, seemingly generic and lacking precision, and open to interpretation (this rather imprecise result being the fruit of a compromise reached after several years of discussions between the TSO, then between the member states). At this point, some unclear aspects will probably be left to each TSO (recharging strategy, "normal state charging"), while another aspect ("alert state sizing") will be dealt with through a EU level cost benefit analysis (CBA).

In this paper, following a recap of the development of the grid code, we aim to provide a clear and precise interpretation of the implications of the requirements for batteries providing FCR in accordance with SOGL.

The first part of battery sizing for FCR provision concerns system normal operation. As specified in SOGL, “each FCR provider shall ensure that the FCR from its FCR providing units or groups with limited energy reservoirs are continuously available during normal state”. However, the required capacity greatly depends on the recharging strategy – for example, a battery with a recharging strategy based on a slowly but continuously varying power offset recalculated in real time to adjust the state of charge would only need a much smaller capacity to ensure normal state continuous operation compared to a recharging strategy based on intra-day markets. These elements are today undefined in SOGL, but shall be defined later in the future “synchronous area operational agreement”, or be left up to each TSO.

To this “normal state” capacity, we must add a 15-30 minute storage band that must be reserved to guarantee full FCR power during system alert state, as specified in SOGL. This time period should be defined after the entry into force of SOGL, following propositions of TSO’s based on CBA. However, it is clear that between the choice of 15 and 30 minutes, there will be a significant impact on costs for the same amount of FCR provision. The CBA which are to be conducted to help determine the 15-30 minute requirement, as well as the synchronous area operational agreement which will determine permissible recharging strategies, will need to seriously consider the interest of opting for restrictive rules, by weighing the additional cost (in cost per MW of FCR) against the risk of having a more limited reserve capacity which might indeed reduce system stability in case of a major incident, however probably with a very low probability of occurrence. To give a first idea regarding this last question, this paper proposes a historical frequency analysis of the European electrical grid to quantify the occurrences of the system being in alert state, as well as simulations of batteries with different capacities and different recharging strategies to analyse their response in normal operation and in different hypothetical “worst-case” scenarios.

This paper will then provide an example of how a regulation in the making can influence the deployment of a new technology such as a battery.

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MODELLING AND VALUE OF STORAGE FOR ARBITRAGE AND PEAK CAPACITY IN A HIGH RENEWABLE EUROPEAN POWER SYSTEM

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Keywords

Energy Markets Modelling, Technological Forecasting, Investment, Power System Economics, Energy Infrastructures (Electricity Storage)

Abstract

This paper proposes a retrospective of several years of modelling and research conducted at EDF R&D on the modelling of energy storage in supply-demand equilibrium model. This work was conducted within the framework of a prospective study on the analysis of a European-level high renewable energy mix.
More specifically, the ambition of the analysis was the evaluation of the role that storage could play in the presence of a large amount of non-dispatchable electricity generation to provide services such as energy arbitration and provision of peak capacity. Other services such as frequency regulation or the carryover of investment in the grid have not been studied in this work.

This study implied two EDF R&D tools: first, a long term unit commitment model at the hourly basis called Continental and second, a tool named Investment Loop which adjusts the installed capacities in each zone so as to ensure an optimal production fleet according to the 3h failure (loss load) criterion. We constructed 6 main scenarios with different renewable penetration ratesand analyzed on several countries (Germany, Spain, France and Great-Britain) the interest of storage considering various technical characteristics.

We intend to present an overall introduction on the current research on storage economics at EDF R&D on all the possible value streams pointing at various references. A literature review will then be proposed regarding the two storage services analyzed in details in the specific work discussed (i.e. energy arbitrage & provision of peak capacity), including in particular a review on the so called PEPS studies in France, of the recent REI (*"Réseau Electrique Intelligent")* analysis made by RTE, and of other research (works of Imperial College in England, of UCD in Ireland, etc.).

Then a detailed description of the way storage is taken into account in our models will be provided. We will discuss the minimum modelling features needed to value storage (hourly resolution, several consecutive days modelling horizon), and discuss the impact of some other (deterministic versus stochastic modelling, dynamic & operational constraints modelling, going to sub-hourly modelling, etc.).

Finally, after a description of how the data set was built and used (i.e our base case reproduces a 2011 European Commission scenario proposing a 60% renewable penetration level by 2030 - then we derived some sensitivities from this base case, increasing by 8% steps, the renewable penetration following a simplified approach) and a short discussion on the storage cost hypotheses used (we will stress in particular the quick evolution of battery

prices that calls for a somehow humble approach with regard to the choice of our assumptions), several series of results will be described:

- Interest of 2, 6 and 40h storages in Germany, France and UK
- Sensitivity on some modelling characteristics (activation or not of some so called “dynamic constraints” such as startup cost & minimum power output) on storage value
- Sensitivity on storage duration, from 0 to 40h of storage
- Sensitivity of storage value to the wind & solar penetration

Our results show & quantify that electricity mix with high renewable penetration rates are opportunities for the storage, but that other flexibility levers are often much less costly and are then strong competitors (in particular, peaking thermal units and curtailment of excess energy appear as quite robust and economic solutions). We also point that, as for every asset, the question of storage profitability doesn’t have a binary answer: we highlight how the notion of an “optimal deployment” evolves according to some hypothesis (as, in particular, decreasing storage cost).

However, we point that increasing the renewable share in the mix does not necessarily & systematically imply bigger revenues for the storage: in fact, storage revenues and system gains are deeply dependent on the structure of the production fleet and hypotheses on CO_2 & fuels costs, and some counter intuitive results can be reached (i.e. storage value tends to increase with more wind and power, but in some case, this tendency can be halted or even reversed when going beyond a certain level of wind & solar penetration).

Lastly, the paper will propose some opening for further research. On the modelling side, a more accurate modelling of operational constraints (ramping rate, starting time, etc.), using a sub-hourly resolution, or explicitly modelling the intraday, imbalance and reserve markets might influence the results of the cost-benefits analyses. On the sensitivities on the various hypotheses used, regular updates of our analyses are needed as technology changes quickly, in terms of costs and performance (for wind, solar, batteries, consumption from EV of H_2 mobility, etc.). Lastly, as new technologies are getting more and more widely used, performing full life cycle analyses (taking into account the impact of extracting rare metals for example) would be a useful complement to the technico-economic analyses performed so far.

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PARETO-EFFICIENCY CURVES FOR DESIGNING COST-EFFICIENT ENERGY POLICIES ON THE ELECTRICITY SECTOR

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Keywords

Pareto-efficiency, energy policy design, decarbonization

Abstract

The advent of liberalized electricity markets transformed the concerns of long-term planning towards the efficient design and implementation of energy policies capable of driving the system. The power sector is expected to pave the way for decarbonizing the energy systems, but market fails on dealing with environmental externalities and system reliability issues (IEA 2006), so some kind of public intervention (e.g. energy policies, regulatory framework, market redesign) might be key for addressing ambitious carbon reduction goals.

Today, the increasing shares of variable renewable energies (VRE) is producing relevant market distortions and system integration challenges, to the extent that it is setting the ground for renewed security of supply issues related to capacity adequacy, reliability and flexibility challenges, which hinders the stability of the system (Druce et al. 2015), deterring further CO_2 emission reductions and increasing system costs, as for the ongoing outcomes of Germany's Energiewende. Thus, analysing the interplays between VRE integration, flexibility, CO2 emissions and costs seems crucial on the design of effective policies for attaining decarbonization objectives. The contribution of this paper is relevant in the sense that it develops a comprehensive methodology using a partial equilibrium model of the electricity sector to build Pareto-efficiency curves that can be used for crafting cost-efficient decarbonization policies.

A case study based on the French power system is presented. The Energy Transition Act (2015) target 96% of CO2 offsets compared to 1990's levels, and up to 80% renewable energy shares by 2050. The outcomes show that even with the most promising technical progress and significant cost reduction of renewables and smart grid technologies, a market-based policy can only effectively achieve between 12 - 18% of VRE shares without subsidies, and similar CO_2 emissions levels than during the 1990's in the absence of any CO_2 reduction incentive. Thus, a stringent CO_2 policy of 50g/KWh together with a Renewable Portfolio Standard would be required to attain these ambitious objectives targeted.

The marginal abatement cost of such policies can be appropriately assessed through the methodology proposed. The cost for attaining the objectives defined on the french Act ranges between 3% and 25%, depending on the scenario. The trade-offs dealing with decarbonization goals and cost overruns are also discussed.

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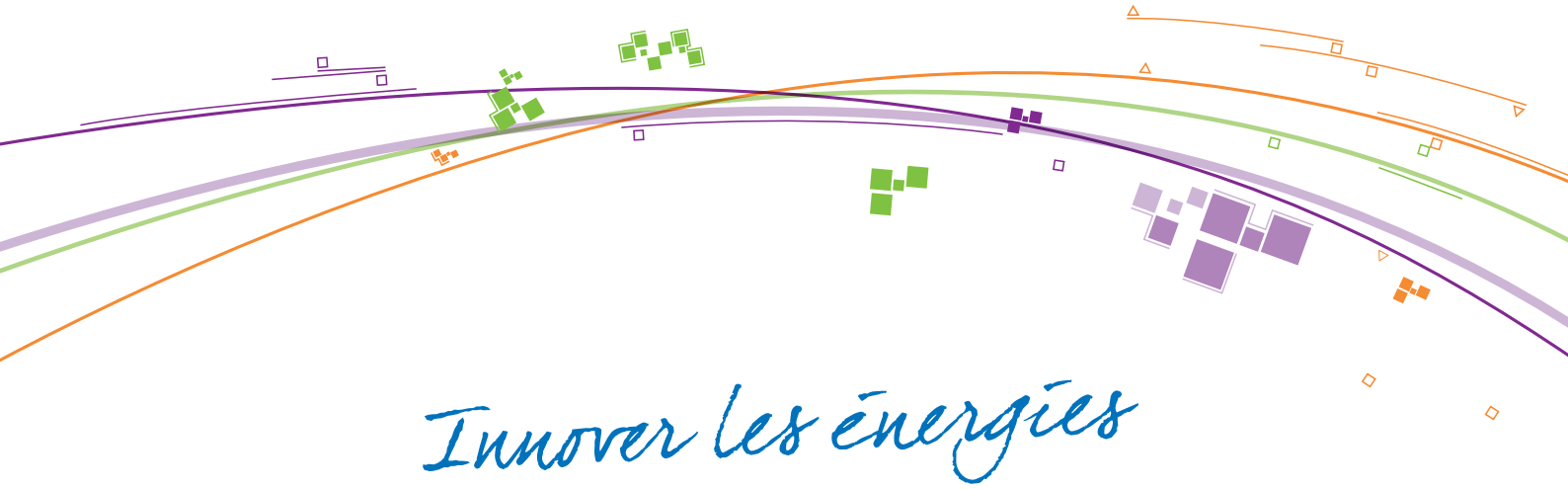
References

[1] Druce, Richard et al. 2015. *System Integration Costs for Alternative Low Carbon Generation Technologies – Policy Implications*. London

[2] IEA. 2006. “Chapter 6. When Do Liberalised Electricity Markets Fail?” In *Lessons from Liberalised Electricity Markets*, Paris, France, 155–70.

https://www.iea.org/publications/freepublications/publication/LessonsNet.pdf



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