Three Investment Scenarios for Future Nuclear Reactors in Europe

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Abstract - **While nuclear power may experience a technological breakthrough in Europe with Generation IV nuclear reactors within a few decades (2040), several events and drivers could question this possibility: as the Fukushima accident, the climate issues and the electricity market liberalization.**
This paper analyzes how the necessary conditions for their industrial development from now up to 2040 can be either favorable or detrimental to future nuclear reactors compared with other technologies and according to four main investment drivers: 1) technical change, 2) policy, 3) market and 4) power company drivers.
Twenty-four scenarios have been identified through structural analysis, with only three proving to be favorable to the development of future nuclear reactors.

***Index Terms*—Power System Economics, Electricity Investments, Nuclear Energies**

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I. INTRODUCTION

In a context of post-Fukushima nuclear development and climate protection, this article addresses the issue of investment in future nuclear technologies in Europe, and in particular Generation IV Nuclear Reactors or Fast Reactors (FR). The MIT publication called *The future of nuclear power after Fukushima* (Joskow and Parsons 2012) reports the expected growth of nuclear power in the world fleet (1% per year through 2035 in OECD countries and 6% per year in non-OECD countries through 2035). This report states that nuclear growth will not be significantly reduced, except in Germany, Japan and Switzerland, which would mean an increased consumption of natural uranium. This nuclear growth and carbon reduction measures such as in the *European Climate Action and Renewable Energy Package* (Da Costa *et al.* 2009) could make FRs a viable choice for further electricity generation capacities.

This technology based on fast neutrons instead of thermal neutrons uses natural uranium more effectively and could ensure several thousand years of nuclear generation, whereas identified resources in uranium only allow for about one century of generation with thermal neutrons reactors (OECD and IAEA 2012). Yet, the thermal neutron technology represents the most common technology in use. It is the predominant technology used for Generation II reactors which represent the majority of reactors currently in operation in the world. This technology has also been chosen for the Generation III reactors that are currently under construction in France (Flamanville), Finland (Olkiluoto) and China (Taishan). Generation IV is still at a research & development stage in several countries such as France, Russia, India and China. Beyond the better use of natural uranium, FRs are also capable of recycling not only the plutonium it uses and but also that produced by fuels from thermal neutrons reactors. FRs contribute to long-term waste management thanks to the transmutation of minor actinides.

The industrial deployment of this technology is expected to be possible from 2040, at least for the French FR given its maturity and the objectives of the French research program (Ministère du Développement durable 2013). The question is to assess the potential penetration of this technology on the European market within this timescale: despite its attractiveness, the context may be unfavorable given the uncertainties that liberalization brings to the electricity market regarding prices and pricing, sector organization, corporate structures, etc. and thus investments (Rogner and Langlois 2001). The changes in the generation mix and the potential integration of FRs in this mix from 2040 depends, of course, on many other factors such as climate and energy policies. In the end, however, is it determined by the decisions of power generation companies, who invest in new capacities in order to replace their ageing capacities and to satisfy a growing demand. This is why we have chosen to focus on investors, i.e. power generation companies, and to analyze their behavior regarding investments in generation capacities in general and not specifically in the nuclear sector.

This article therefore examines two research issues: 1) What are the drivers for investors' decisions on the European electricity market regarding investments in power generation capacities? 2) How do they affect the development of the European generation mix and the integration of FRs in this mix?

We focus on France, Germany, the United Kingdom, Spain and Italy, for they represent 65% of European Union (EU27) power generation (Grand and Veyrenc 2011). The timescale is fixed to roughly 2040, for most reference scenarios are situated between 2030 and 2050. Since we aim to cast light on the future according to today's most certain data, the panel of technologies considers those most commonly used on an industrial scale and disregards technologies that are not yet quite developed such as biomass, geothermal energy, carbon capture and storage, and small modular reactors (SMR) in the nuclear field.

As main results, our analysis identifies the three key drivers: 1) policy (divided into climate policy and nuclear policy), 2) technical change and 3) market drivers; that are behind the choices of investors and construction scenarios for the European generation mix based on the development of these drivers in the future. Our structural analysis shows that the market driver proves negligible compared with the two others and that business-as-usual scenarios are not favourable to FRs. Climate policy appears to be the *sine qua non* condition for further nuclear development; this is why both strong and moderate pro-nuclear policies are compatible with FR investment in the "climate constraint" scenarios, where nuclear is the only economically viable alternative. The "totally green" scenarios combined to a strong pro-nuclear policy assumption are also favourable to FRs in a context of flourishing renewables. Three scenarios favourable to FR investment have thus been identified regardless of the market driver; that is to say, they gather the necessary conditions for FR investments.

The paper is divided in three sections. Firstly, Section II provides a literature review describing the common academic approaches to electricity investments and explaining the choice of a strategic foresight methodology to answer our research questions. Secondly, the methodology itself – structural analysis – is presented and applied in Section III. Based on both a literature review and interviews with experts, three key drivers are identified, with each driver being described by several variables and the interactions between analyzed and quantified. Thirdly, Section IV describes scenarios for the future generation mix which are built on a couple of low/high assumptions for each driver. The interactions between variables are processed with the structural analysis software called MICMAC (Godet 2008, 2001, 2000) in order to assess the relative importance of the different variables and rank the scenarios. Lastly, the most favorable scenarios for the penetration of Generation IV nuclear

reactors are thus identified and then discussed in Section IV.

II. LITERATURE REVIEW

A. Investment decisions in energy: short-term opportunities rather than long-term strategies?

The dominant economic theory used for electricity investment choices in the second half of the 20th century was the Cost–Benefit analysis (Chick 2007). It takes its roots in the Welfare Economics theories founded in the 1930s and 1940s (Hicks 1939; Pigou 1924; Samuelson 1943; Allais 1943), and became known in the early fifties (Massé 1953; Boiteux 1956). It remained the dominant academic current until the start of the liberalization process in 1986, though it had already started to be questioned . Empirically, with the Suez crisis in 1956, works tended to show the shortcomings in the Cost-Benefit analysis: it does not properly include risks and in particular exogenous risks, like the one on fuel supply (Chick 2007). Theoretically, new economics in the 1940s and 1950s addressed the issues of the risk on decision makers' rationality (Friedman and Savage 1948; Neumann and Morgenstern 1944). These theories were expanded in the 1960s and 1970s by addressing the issue of public decisions in uncertain environments (Arrow 1965; Henry 1974; Weisbrod 1964). Besides note that in the context of a liberalized market Cost-Benefit analysis is still a classic tool for electricity investment choices: shorter payback periods and higher rates of return are considered (Bibas 2011).

History shows that the Cost-Benefit analysis led state choices about electricity investments mostly in France and partly in other European countries, but tended to be forgotten in crisis contexts (Suez Crisis, oil crises) in favor of national security of supply or national employment protection (Chick 2007). Cost-benefit analysis is thus an efficient approach to introduce economic rationality into choices but not the appropriate tool to describe investment choices in a realistic manner. Indeed, long-term economic rationality is neither the only driver, nor the main one for investment choices. Choices can been seen and considered on two levels: individual or collective, and are made according to both of strategy and opportunity. This classic opposition between strategy and opportunity has led to a new trend (Chabaud and Messeghem 2010) based on Venkataraman's work (Venkataraman 1997). Given that a decision-making process is confronted with a context of complexity and the need for quick action, they argue that a decision often seizes an opportunity instead of being based on a long-term rational strategy. It is thus not the result of a precise analysis of all the parameters at stake, but of a more intuitive decision or an exploratory decision (Alvarez and Barney 2007). Chabaud and Messeghem explain this side of decision-making as a way of optimizing resources by seizing opportunities.

This latter interpretation is very consistent with the reactions observed after the oil crises in Europe. Many countries returned to using domestic coal, started new exploration for local resources or accelerated their nuclear programs, seizing every immediate opportunity to reduce energy dependence in the long term.

Since long-term economic rationality is neither the only driver nor the main one for investment choices, we thus seek to identify the actual drivers for investment behavior.

B. Prospective approaches of energy: strategic foresight methods

Our research aims at studying investment choices beyond economic rationality and taking into account such behavior in the description of the investment process. As said in the introduction, there are two steps to our research problem:

- Identifying the drivers for investors' decisions;
- Analyzing their effects on future changes: elaboration of scenarios illustrating future trends in a descriptive and exploratory approach (in opposition to normative: there are no fixed objectives).

Such an approach clearly belongs to the field of strategic foresight, in opposition to other scenario-building techniques: forecasting or fictional futures (Bland and Westlake 2013). For the first step, foresight methods usually recommend conducting interviews or a set of collective workshops. For the second, it is necessary to isolate the key variables influencing the system's development and to build the scenarios on these variables. Among strategic foresight manuals and literature, the works of Godet describe a full set of tools to practice strategic foresight from problem definition to scenario probabilities (Godet 2000; Godet and Roubelat 2000; Godet 2001, 2002, 2008). Structural analysis using the MICMAC tool is one way of identifying all the drivers for a system especially those determining its development. This method focuses on clarifying the data of the problem, which is consistent with the purpose of our study.

Applications of these methods to the electricity and energy fields are numerous, addressing the issue of market liberalization as in work by Bergman *et al.* (2006), who built development scenarios for the business environment in the electricity industry, according to different assumptions of success of the European market reform in Finland. Another example is energy saving as described by Wang, Wang and Zhao (2008) who apply these methods to the major barriers which prevent the practice of energy saving in China and the interactions among them. They can be used to assess low carbon scenarios in the UK and worldwide as

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shown in Hughes and Strachan (2010). Schenk and Moll (2007) also use them for energy scenarios, showing that physical variables (e.g. amount of energy generation) rather than monetary indicators provide additional insights in scenario analysis.
The limits of Godet's methods are, however, described by Gonod, who identifies its subjectivity, its static character and the lack of uncertainty assessment as its main weaknesses, the two latters being a consequence of the former (Gonod and Gurtler 2002). He proposes a different approach of foresight which is more dynamic and open to deep structural changes in the system under study (Gonod 2006). Approaches similar to Godet's have thus been developed with a stronger focus on the collaborative aspects of foresight methods in order to lessen their subjectivity. Hines and Bishop (2006) insist on the bias of interviewed participants and establish a typology of participants' profiles (Laggards, True Believers, etc.) to identify common biases in such foresight approaches and separate them from relevant collected data. Markard, Stadelmann and Truffer (2009) also point out that scenarios neglect the co-development of technological and societal processes and that they lack the theoretical foundation explaining the interactions between the strategies of different players; they build a methodology that emphasizes the links between technological variables, player networks and institutional structures in order to identify plausible future innovation, in the case of biogas.
Hughes, Strachan and Gross (2013) show that the level of uncertainty affects the relevance of low-carbon scenarios. They propose to reduce uncertainty by a player-based system with a more in-depth analysis of the interactions between them, thereby leading to better scenarios.
However, in a recent review of foresight methods (Coates, Durance and Godet 2010) and reflections on the numerous uses of strategic foresight (Godet 2010; Durance and Godet 2010), the authors remind us that the validity of the analysis conducted with their tools is not only dependent on the tool's performance, but also on the user's rigorous approach and common sense. Bearing in mind the limits cited above and the existing bias, we chose Godet's structural analysis method to pursue this prospective study.

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III. Framework of the Study: Structural Analysis

This section describes the structural analysis performed in an attempt to answers to our research questions within a rigorous methodological framework. Since we are interested in the investment decision of the power generating company, the system under study thus comprises the power generation company and the set of investing conditions with which it is confronted.

A. Retrospective analysis: generation mix and market liberalization in Europe

The first step of our analysis must look back on historical aspects in order to determine the constants in human behaviour and to get some perspective on the bias of our time: it is commonplace to say that 'History does not repeat itself, but human behaviour certainly does'. In the history of the European market, there are two main processes to be studied: 1) the constitution of the European generation mix from the fifties up to now in order to understand past investment choices, and 2) the European market liberalization that started in the nineties in order to understand the kind of context with which current investors are confronted.

This historical analysis shows that European countries have massively privileged local resources (such as coal in Germany) or the development of a locally well-mastered technology when local resources were poor (such as nuclear in France). This tendency was reinforced after the two oil crises in the seventies, leading European power companies to ensure the security of supply at high costs. The driver to these decisions was the state policy with the purpose to ensure energy independency.

After the oil-price slumps in the eighties, a market reform was implemented in Europe in the nineties to create a single European competitive market out of all the national markets in place, which were often integrated monopolistic markets (Grand and Veyrenc 2011; Hansen *et al.* 2010). The reform was unequally applied in the different countries (to a great extent in the UK, which was a pioneer of liberalization and very little in France, where the natural monopoly model was considered a success within the rule of the Ramsey-Boiteux pricing (Baumol 1977), leading to various market structures and concentrations represented very different environments for investors. The unification of the European market remains unachieved, mostly because of a lack of interconnections between countries (Grand and Veyrenc 2011). Market structure is thus another driver for investors' decisions.

B. Drivers: from investment conditions and power companies

1) Investment conditions in electricity generation technologies

As for listing the variables, we conducted interviews of experts taking into account all the bias of such interviews, before exploiting this information and expanding on it with a close review of related literature. Sixteen experts who are known for their visions in their area were interviewed: 3 technology development experts in the nuclear field and 9 policy experts from a research institution (the CEA) and embassies (12 countries in Europe, North America and Asia), 4 economic experts from energy companies (EDF, Areva) and 1 independent consultant.

Our historical approach showed that drivers were state policy (energy independency and local employment), the local technology and the market structure.

As a result of these interviews and our literature study, we were able to distinguish three mains drivers that shape the investing conditions for power generation companies: 1) State policy driver; 2) Market driver; 3) Technical driver.

From a general point of view, the state's priorities are usually the security of supply and energy independency. However, there is no real electricity supply problem in the particular context of Europe: it is more the case in emerging countries such as China and India with high growth. The technological advancement of the country is a driver that goes hand in hand with demand satisfaction in emerging countries. In Europe, the energy policy is more about climate change, renewable energies and nuclear acceptance (reducing the use of fossil fuels points in the direction of energy independency). Today and within our European scope, the policy driver thus contains four dimensions:

- Climate policy, which is divided into two aspects: carbon policy and renewable policy;
  - Carbon policy, which will determine the incentives regarding carbon emissions and promote low-carbon energies, which are at the heart of our study.
  - Renewable policy, which is closely related to carbon policy, can be described in Europe by four kinds of tools: feed-in tariffs, green certificates, tenders and fiscal incentives (Bordier 2008).
- Nuclear policy: the use of this energy can be controversial according to the national context, with the positions in the five countries investigated being very different. France has historically adopted a strongly pro-nuclear stance; the importance of the nuclear facilities and expertise inherited from the past should maintain France in a strong pro-nuclear stance. The UK has adopted a moderate pro-nuclear stance , although recent development in nuclear in the UK shows strong support, as the agreement with EDF for the Hinkley Point shows (Department of Energy & Climate Change and Prime Minister's Office 2013); however, the government's will never to directly support financially nuclear makes UK policy "moderately pro nuclear". On the other hand Germany, Italy and Spain have adopted an anti-nuclear position; for pro-nuclear countries, we add the "strike price" variable to describe the nuclear policy more accurately;
- Electricity market reform policy, which will have a direct influence on the investors' environment and the investors' profiles themselves. To elaborate our scenario, we included this driver in the second category: 'market driver'.

The market driver contains several aspects:

- Level of concentration and competition of the market that can be characterized by the number of players present on the market and the Herfindahl–Hirschman Index (HHI[1]);
- Market policy led by the country, which will have an influence on both the market structure through market reform policy and market coordination, which is essential to investors' decisions.

As a first approach, we have considered that the market reform policy is described by the choice whether to develop interconnections, and more generally, the electricity grid. The "market structure" driver has thus been considered under both angles of concentration and interconnections. As for market coordination, investment coordination is described by the different financing methods: corporate financing, project financing, hybrid method mixing the two latter, or other original financing methods (e.g., financing from the future customers) (OECD 2009; IAEA 2009).

The technical driver (regarding coal, gas, nuclear, hydro, wind, solar) includes building and generation costs, as well as load factors that will directly impact the expected profits, but also all the parameters that will make the technology more or less easy to acquire for the investor, i.e. the construction timescale, the average size of the plant for this technology, and the technology complexity. Since the perception of technology complexity depends on every company according to its own expertise, we will not include it in this technical driver but in the drivers proper to the company.

The different decision variables corresponding to the three main drivers are listed in Table I.

[1] HHI definition, with s_i the market share of firm i in the market, and N the number of firms:

$$H = \sum_{i=1}^{N} s_i^2$$

The lower HHI is, the more the market is competitive, and the higher HHI is, the more the market is concentrated.

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N°	Variable	Related Driver
1	Carbon tax (€/tCO_2)	Policy Driver
2	CO_2 quota	
3	Feed-in tariffs for renewables (€/MWh)	
4	Green certificates for renewables	
5	Tenders for renewables	
6	Fiscal incentive for renewables	
7	Nuclear position	
8	Nuclear strike price (€/MWh)	
9	Stability of policy	
10	HHI concentration index	Market Driver
11	Development of grid and interconnections	
17	Corporate financing	
18	Project financing	
19	Hybdrid financing method (corporate and project financing)	
20	Other original financing method	
12	Construction costs (€/MW)	Technical Change Driver
13	Generation costs (€/MWh)	
14	Building period (year)	
15	Size of plant (MW)	
16	Load factor (%)	
21	Shareholding structure	Company driver
22	Market Capitalization	
23	Annual Production	
24	Generation Mix	
25	Market share	
26	Annual revenue	

Table I: Decision variables for each driver

2) Drivers from characteristics of companies

In order to understand investment choices, it is relevant to compare investor profiles and technology investment conditions: for instance, capitalistic investments such as coal or nuclear plants are *a priori* achievable only for companies with sufficient revenue and capitalization to support the building costs, and low-capital cost technologies such as small renewable facilities are at the reach of all investors. Nonetheless, the thorough investigation of investment conditions shows that original financing methods such as conjoint investment from a consortium of power generation companies or financing from long-term electricity purchasers can broaden the scope of companies able to make capitalistic investments.

The second step of our analysis thus consists in defining who the investors are and how their characteristics will influence their own investment decisions.

Investor profiles can be analyzed through a few key characteristics that are:

- Shareholding structure, which will give an indication on the investment strategy of the company (private shareholders: institutional, public float, or state shareholders: state, ministry, local authority, and weight of the different types of shareholders);
- Market capitalization and annual revenue, which indicate the size of the company from a financial point of view and the size of the investments the company can support,
- Total annual production, that indicate the size of the company from an industrial point of view;
- Generation mix, which shows the company's fields of expertise;
- Market shares on markets where the company is active, which show the international scope of the company.

An overview of the companies falling within our scope shows that most of the current power generation companies are former historical operators who used to be in a dominant market position (Grand and Veyrenc 2011). Their shareholders are state players such as the government, a ministry, or local communities, institutional investors such as banks and insurance companies, and private shareholders (public float), with the weight of each type of shareholder depending on the national position towards market reform and the specific history of the company. Their annual revenue and market capitalization represent several dozen billion euros and annual production of around a hundred TWh (EDF *et al.* 2012). Their dominant technologies are mostly coal and gas (and nuclear for EDF). Most of them have crossed the border of their initial market and have started being active on neighboring markets: e.g. EDF is present in the UK and Italy, and EOn in the UK, Italy and Spain. We can also observe concentrating movements between these companies: for instance, the Italian operator ENEL owns the

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Spanish Endesa, the French operator EDF owns British Energy, and the Spanish operator Iberdrola owns Scottish Power.

Yet another type of profile seems to be emerging with the market reform, the one of small power companies. Such companies are generally young, dating from the nineties or 2000 such as the wind operator Theolia or the solar operator Solaire Direct. Their shareholding structure boasts no state players; their revenue is around a few million euros and their annual production less than 1 TWh. They mostly specialize in one technology since their size does not allow them to diversify, mostly in recent technologies such as renewables or CCGT. They can be local or international operators, representing minor market shares in any case.

As mentioned above, national positions regarding the market reform differ from one country to another, which affects the development of power generation companies. France, Germany and Spain tend to protect their historical operators on their domestic markets and promote their international development thanks to the reform; the UK and Italy are really promoting competition on their own market, with Italy limiting market shares for the different players on the Italian market for instance. The development of investors profiles towards multinational concentrated companies or towards small power operators will depend on the changes to the global market structure in association with the market reform policies led in EU countries.

Shareholding structure	Company driver
Market Capitalization	
Annual Production	
Generation Mix	
Market share	
Annual revenue	

Table II: Company drivers

C. Analysis of interactions: matrix of direct influences and dependences

The MICMAC method consists in assessing the relative influence of all variables upon another[2] in order to fill a matrix called the Matrix of Direct Influences.

Information extracted from literature review and interviews allowed us to fill the Matrix of Direct Influences and Dependencies[3]. Since filling the Matrix by the experts would need a training session and a workshop in presence of all experts, the matrix was not given to them to be filled in but was filled in using a compilation of their answers and the results of the literature review as well.

[2] For each variable, its influence on every other variable is quantified from 0 to 3, the value 0 corresponding to no influence at all, and 3 to a strong influence. The letter P is used when a potential influence is sensed, but not clearly indentified. In the matrix of direct influences, each line contains the values attributed to the variable's influence on every variable in the column. Therefore the lines show how much influence the variables have on the other ones and the columns show how much the variables depend on the other ones.

[3] According to observations by Godet (2001), an optimal filling of the matrix corresponds to approximately 20%; our matrix has a filling rate of 27.8%, which is reasonably close.

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	1 : Carbon tax	2 : CO2 quota	3 : Feed-in tariffs for renewables	4 : Green certificates	5 : Tenders for renewables	6 : Fiscal incentive for renewables	7 : Nuclear position	8 : Nuclear strike price	9 : Stability of policy	10 : HHI	11 : Development of grid	12 : Construction cost Euro/MW	13 : Generation cost Euro/MWh	14 : Building period	15 : Size of plant	16 : Load factor	17 : Corporate financing	18 : Project financing	19 : Hybdrid financing method	20 : Other original financing method	21 : Shareholding structure	22 : Market Capitalization	23 : Annual Production	24 : Generation Mix	25 : Market share	26 : Annual revenue
1 : Carbon tax	0	3	3	3	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	3	0	3
2 : CO2 quota	3	0	3	3	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	3	0	3
3 : Feed-in tariffs for renewables	3	3	0	3	3	3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	3	0	3
4 : Green certificates	3	3	3	0	3	3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	3	0	3
5 : Tenders for renewables	3	3	3	3	0	3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	3	0	3
6 : Fiscal incentive for renewables	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	3	0	3
7 : Nuclear position	P	P	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	3	0	0
8 : Nuclear strike price	P	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	3	0	3
9 : Stability of policy	3	3	3	3	3	3	3	3	0	0	3	0	0	0	0	0	1	1	1	1	3	0	0	3	0	0
10 : HHI	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 : Development of grid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
12 : Construction cost Euro/MW	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	0	3	0	2	0	0
13 : Generation cost Euro/MWh	3	3	3	3	3	3	0	3	0	0	0	0	0	0	2	0	0	0	0	0	0	3	3	3	0	3
14 : Building period	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 : Size of plant	0	0	0	0	0	0	0	0	0	0	2	3	0	3	0	0	3	3	3	3	0	0	3	3	3	0
16 : Load factor	0	0	3	3	3	3	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	3	3	0	0
17 : Corporate financing	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	1	0	0
18 : Project financing	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	1	0	0
19 : Hybdrid financing method	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	1	0	0
20 : Other original financing method	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	1	0	0
21 : Shareholding structure	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	3	3	3	0	3	0	3	0	0
22 : Market Capitalization	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3	0	3	3	3	3	3	0	0	0	0	0
23 : Annual Production	0	0	0	0	0	0	0	0	0	3	3	0	3	0	2	1	0	0	0	0	0	0	0	0	3	3
24 : Generation Mix	3	3	3	3	3	3	2	0	0	0	3	1	0	1	1	0	1	1	1	1	0	0	3	0	0	0
25 : Market share	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0
26 : Annual revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	3	0	0	3	0

Table III: Matrix of direct influences

The influence of a variable on another is considered direct if the value of the influencing variable appears in the definition of the influenced variable. For instance, Feed-in-Tariffs are designed according to technology generation costs, revenues of power generation companies are partly determined by incentives (Feed-in-Tariffs, fiscal incentives, carbon price or carbon tax). It is important to note that filling in the matrix is about identifying crossed influences between the variables in our list. It does not mean that the variables depend exclusively on other variables coming from the list. In the next paragraph, we detail how the matrix was filled in.

Policy drivers

Incentives for renewable and carbon are designed based on: the global policy of the country regarding this matter, which means that all climate policy incentives are influenced by one another and are influenced by the global stability of climate policy. The costs of technologies have a direct influence on shaping incentives (FiT, price of carbon, fiscal incentive, etc.) so that the incentive plays its role well. The technical characteristics affecting the production and thus revenue are also influential, i.e. the load factor (for renewables that face intermittency issues, not for carbon prices, which are intended so that the carbon costs for the company be proportional to its carbon emitting generation). Incentives are also shaped according to the existing mix in the country that the policy wants to change, i.e. the generation mix of all power generation companies. Since all these influence are direct and very obvious, they are assessed with the maximum value of 3.

Carbon incentives could be influenced by the country's nuclear stance, since a pro-nuclear stance can favor a low carbon policy: potential influence.

The nuclear stance is a long-term political decision that goes back to the 80s & 90s and the inertia of which is hardly likely to be influenced by other listed drivers. However, some drivers have a moderate or weak influence on it: sometimes it can be part of a low-carbon policy. It is influenced by the stability of policy (in the US, the possibility of a radical change in energy policy makes it impossible to have a strong pro-nuclear policy); the profile of shareholders from power generating companies may have more or less influence on the political opinion on nuclear since the presence of government entities in the shareholders supposes common interests or at least closer interaction between the state and the company. Moreover, the existing generation mix of

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companies' influences the state's nuclear stance, since the lifespan of power plants causes certain inertia. A national electricity mix relying on nuclear for 75% of the generation is less likely to switch to an anti-nuclear position than a mix with 20% nuclear share.

The nuclear strike price (the incentive identified) depends on the state's nuclear stance and the stability of its policy, as well as been designed according to the generation cost.

Policy stability influences many other drivers rather than depends on them, but no direct influence from the other drivers has been identified: in fact, it depends on many factors, some of them outside the scope under investigation, like the political context and organization of the country, and is mostly the result of indirect influences of others drivers.

Market drivers

The HHI depend on the market shares of the companies that can be calculated using the production or company size, which is why the corresponding indicators were also listed as influential on the HHI.

The development of grid depends on: the stability of policy since real perseverance is needed to establish new lines; the concentration of the market since the multiplication of players will make more interconnections necessary; the size of plants since it is an indicator of a centralized or decentralized market (smaller plants means more plants and therefore more interconnections); the load factors: low load factors means there is a need for more capacity and more interconnections.

The choice of a financing method is mostly influenced by the financial indicators of the size of the company: market capitalization, market share and annual revenue to a lesser extent. The choice is also influenced by:

- the shareholding structure of the company: the private or public profile of the company offers different kinds of financial guarantee and thus leads to different financing methods;
- the size of the project, which determines the total investment cost and building time, so the payback period;
- the existing mix, since it shows the company's field of expertise and can orientate the choice of financing method;
- policy incentives: supporting incentives, since they can offer financing structures (such as tenders) or financial security (feed-in tariffs/strike price, fiscal incentive, green certificates);
- carbon-related incentives, since they increase risk on profitability.

Let us mention that, of course, the cost of financing will depend on the generation cost, investment cost, all policy incentives including carbon incentives; but it is not the cost of financing that is examined here, it is the choice of the financing method.

Technical drivers

The MW construction cost can vary depending on the construction timescale since the longer it lasts, the higher the €/MW cost and the size of the plant, due to a potential scale of economies.

The MWh generation cost is influenced by the construction cost to the MW and the amount of generation (to evaluate variable costs). Of course, generation costs also depend on others parameters that were not identified as drivers per se: cost of fuel, cost of workforce, etc. (they are all included in the 'generation cost' driver).

The construction timescale mostly depends on the size of plant but also – to a lesser extent – on the existing mix of the generation companies, since it indicates their level of expertise in the different technologies

The load factor is mostly a technical parameter imposed by the technology: base technologies such as coal and nuclear are required to have an approximate load factor of 80%, while intermittent renewable technologies have an average load factor of 20-25%. However, according to variations in demand, this load factor can be changed: it is particularly true for peak technologies such as gas or hydro, but it can also affect base technologies. This is why the production of the company is assessed to have a weak influence on the load factor.

Company drivers

The shareholding structure can be mostly influenced by policy stability, which will keep the same company profile through time (public/private). It can also be influenced by the size of the capital, i.e. the market capitalization, since a large company is more likely to be a former state-owned company with still government entities among the shareholders, than a small company born with the liberalization process. Lastly, it can be influenced by the policies and incentives in general.

The market capitalization can be calculated by different methods. Since the calculation depends on shareholder expectations, it mostly depends on the shareholding structure of the company; and since it involves the company's profits in most methods, revenues and costs are considered highly influential. Financing choices are considered to influence costs so are listed to have a small influence. As said above, other costs such as fuel costs are influential but do not appear here since they are already included in generation costs.

The value of annual production of a company is above all conditioned by demand and its capacity. On a more detailed level, it depends on:

- the generation mix,
- the size of the plants and their load factors, since the plants will generate more or less electricity over the year according to their capacity and the type of technology (base, intermittent, peak);

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- generation costs of the technologies;
- grid constraints;
- incentives for carbon emissions (to a lesser extent).

Positive incentives on renewables and nuclear are not considered influential since the renewable technologies considered here are intermittent and thus have priority to sell, and that nuclear is supposed to work on a base load. Since coal is also a base-load technology, this means that generation from gas could mostly be impacted.

The generation mix depends on the installed mix and how it can be used to respond to demand and thus is influenced by:

- the size of plants (they define the installed mix);
- the load factors of the technologies in the mix (since they give the actual generation of the installed capacity);
- generation costs (merit order);
- investment costs, thus involving size of plants and MW investment costs (since the necessity to make an investment profitable can condition the load factor);
- the incentives to use some technologies rather than others: support incentives for renewables or nuclear, or negative incentives for fossil technologies.

The market share of a power generation company is usually calculated in installed capacity or in generation (for instance to calculate the HHI indicators in European Commission reports); the traditional definition of market share is based on the company's revenue. The market share thus depends on the size of plants (installed capacity), the annual generation or the annual revenue (for the theoretical definition).

The annual revenue is influenced by the annual production and all the incentives affecting the revenue.

IV. Results: Building Scenarios for Generation IV

A. Development assumptions for all drivers

In order to build investment scenarios based on these drivers, it is necessary to extract assumptions from our previous analysis regarding their development over the timescales of our study. Low and high assumptions for each dimension of the policy driver have been formulated.

We have identified a strong climate policy scenario and a moderate climate policy scenario that can be quantified by their carbon price ranges, with carbon pricing being the key tool of climate policy. Today EU ETS has had low carbon prices around a dozen US$/ton CO_2 for a few years. Strong climate policy would imply increasing this price, which could be achieved by the mean of a reform of the carbon market or a carbon tax. Given the European objectives of 3x20 carbon prices are expected to rise, the question is how much. The moderate climate policy would consist pursuing the EU ETS system with reforms, leading carbon pricing to increase from a dozen $/metric ton to $45/t$CO_2$ in 2040. A strong climate policy would increase the carbon price up to 120 $/t CO_2 in 2040 (IEA 2012). The renewable policy is closely related to the carbon policy, as the European Climate-Energy Package shows therefore a strong climate policy scenario corresponds to strong incentives both in terms of long-term support and high amounts, whereas the low assumption would correspond to current trends (Bordier 2008). We assume that nuclear policies do not change within the considered period[4].

In theory the liberalization should lead the market to decentralize, which is far from being obvious in the case of European electricity market. We will describe concentration assumptions using the HHI: as in the European Commission Guidelines on competition, we consider a market in which the HHI is lower than 1000 as competitive and low concentrated, whereas a market in which the HHI is in excess of 2000 is highly concentrated. By observing the HHI of different European countries, we can see that some countries have managed to go under 1000 (UK, Italy), whereas others remain very concentrated (France's HHI is above 7000). Concentration movements since the beginning of the liberalization process are not in favor of a European deconcentration. For this reason we make both a high and a low concentration hypothesis.

A high concentration assumption goes along with a low development of interconnections; a low concentration market with a strong development of interconnections. Let us notice that development of interconnections is an issue due to systematic strong local opposition. As for the different financing methods, we consider the flexibility of choices in financing as a static decision variable and thus make no assumption regarding their potential development.

Among the technologies being studied, coal, gas, hydro and nuclear are considered to be time-tested and expect less progress than wind and solar[5]. The technical driver thus corresponds mostly to the expected technical change for these two recent

[4] This assumption may be considered a limit in the elaboration of scenarios; nevertheless, such political stances commit long-term industrial behaviors and for this reason it is relevant to assume a certain degree of inertia in the pro- or anti-nuclear stance.

[5] It is true that nuclear technologies are still experiencing innovation, but even new generations of nuclear reactors (Generation III, Generation IV) are based on experienced concepts: pressurized water reactors for Generation III, which is one of the most current concepts in operation today, and sodium-cooled fast

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renewable technologies, wind and solar. For this driver, we made a high technical change assumption and a low technical change assumption. The technical change would impact construction costs, generation costs and technical constraints of each technology: load factor, average size of plants, construction time; WEO 2011 scenarios allow us to estimate the expected cost reduction (IEA 2012). Since the impact on these different costs is quite homogenous according to the expected progress for one technology, overnight investment cost reduction is a relevant indicator: Table IV gives the orders of magnitude of investment cost reduction for the two assumptions, which shows that progress is mostly expected for solar technologies (PV and CSP).

Technology	Low technical change	High technical change
Onshore wind	10%	20%
Offshore wind	25%	50%
Solar PV (utility and rooftop)	50%	75%
Concentrated solar power	40%	90%

Table IV: Investment cost reduction between 2010 and 2040

Regarding the company drivers, the development in the size of companies naturally follows the assumptions on market concentrations and the HHI. However, since the aim of the study is to assess the reaction of companies to investing conditions and to observe how the development of their mix could be affected, no assumption is made on company drivers.

A total of 24 different scenarios are possible as a result of the number of assumptions:

- high and low assumptions for the climate policy driver, market driver, and technical change driver,
- high, low and medium assumptions for the nuclear policy.

Scenario 1a	strong climate policy	low technical change	concentrated	strong pro-nuclear
Scenario 1b	strong climate policy	low technical change	concentrated	moderate pro-nuclear
Scenario 1c	strong climate policy	low technical change	concentrated	anti-nuclear
Scenario 2a	strong climate policy	low technical change	not concentrated	strong pro-nuclear
Scenario 2b	strong climate policy	low technical change	not concentrated	moderate pro-nuclear
Scenario 2c	strong climate policy	low technical change	not concentrated	anti-nuclear
Scenario 3a	strong climate policy	high technical change	concentrated	strong pro-nuclear
Scenario 3b	strong climate policy	high technical change	concentrated	moderate pro-nuclear
Scenario 3c	strong climate policy	high technical change	concentrated	anti-nuclear
Scenario 4a	strong climate policy	high technical change	not concentrated	strong pro-nuclear
Scenario 4b	strong climate policy	high technical change	not concentrated	moderate pro-nuclear
Scenario 4c	strong climate policy	high technical change	not concentrated	anti-nuclear
Scenario 5a	low climate policy	low technical change	concentrated	strong pro-nuclear
Scenario 5b	low climate policy	low technical change	concentrated	moderate pro-nuclear
Scenario 5c	low climate policy	low technical change	concentrated	anti-nuclear
Scenario 6a	low climate policy	low technical change	not concentrated	strong pro-nuclear
Scenario 6b	low climate policy	low technical change	not concentrated	moderate pro-nuclear
Scenario 6c	low climate policy	low technical change	not concentrated	anti-nuclear
Scenario 7a	low climate policy	high technical change	concentrated	strong pro-nuclear
Scenario 7b	low climate policy	high technical change	concentrated	moderate pro-nuclear
Scenario 7c	low climate policy	high technical change	concentrated	anti-nuclear
Scenario 8a	low climate policy	high technical change	not concentrated	strong pro-nuclear
Scenario 8b	low climate policy	high technical change	not concentrated	moderate pro-nuclear
Scenario 8c	low climate policy	high technical change	not concentrated	anti-nuclear

Table V: 24 possible scenarios

It may not be relevant to describe all 24 scenarios without any kind of sorting: among the identified drivers for investments, we wanted to identify the ones that were the most relevant to scenario building, which was possible thanks to the processing of the structural analysis results with the MICMAC tool.

reactors for Generation IV, the technology of which was experienced in France in the eighties with the Phenix and Superphenix demonstrators, and is today in operation in Russia on a few reactors (BN-600, BN-800).

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B. Sorting key drivers as a result of structural analysis

Using the Matrix of Direct Influences, the MICMAC tool generated the Graph of Direct Influences and Dependences, as shown in Figure 1. On this chart, the more a variable is far on the x-axis, the more it is dependent on other variables; the more a variable is far up the y-axis, the more it has influence on other variables. Therefore the variables contained in the upper left corner of the chart have influence on other ones but do not depend on them and are thus exogenous: they are called "input variables". They tend to condition the system's dynamics. The ones in the upper right corner of the chart, which have influence and depend on other variables, are called "intermediate variables". They can sometimes be considered as the most important variables of the set since any action on these variables cascade throughout the rest of the system. The ones in the bottom right corner depend on other variables but have no influence on them: they are called: "output variables". Their behaviors explain the impact from input and intermediate variables. The ones in the bottom left corner of the chart have no influence on other variables and do not depend on them: they are called "excluded variables" and are the less important ones. They often describe inertial trends that change little over time. Lastly, the "clustered variables" are the ones that are not sufficiently influential or dependent to be included among the previous classifications.

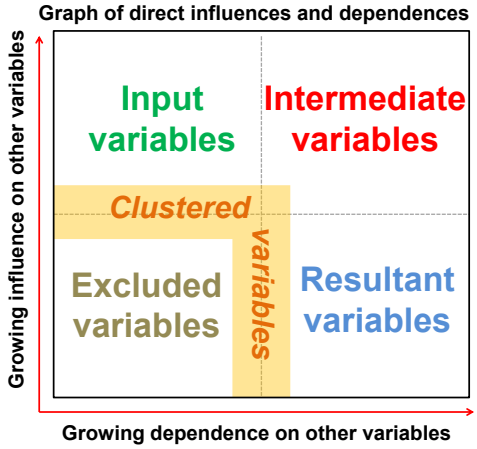

Figure 1: Chart of direct influences and dependences (empty)

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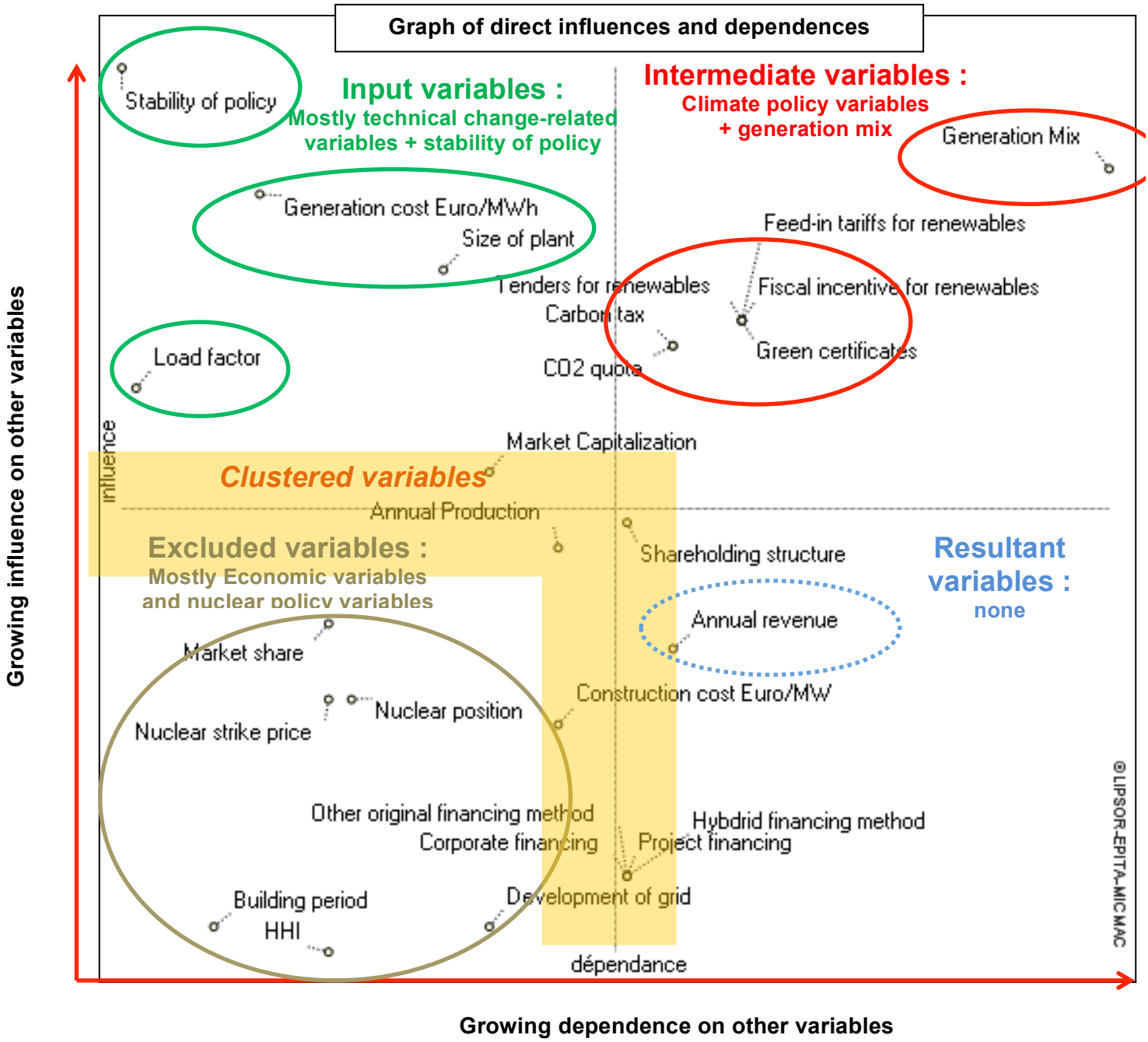

Figure 2: Chart of direct influences and dependences (external and internal variables)

Figure 2 shows that input variables are: policy stability and technical variables (generation costs, size of plant, load factor). Intermediate variables are all the climate policy variables and the generation mix. This is predictable since it means policy instruments are designed according to the technical characteristics of the technology. Nonetheless, technology changes cannot be seen as a direct result of policy (results of encouraging incentives are not direct enough). Generation mix is also a result of the technical characteristics of the technology and policies, as well as influencing the energy policy choices in return.

There are no resultant variables, except for the annual revenue that may considered as one: it is not surprising for this driver, since the annual revenue results from 1) the technology's characteristics such as generation costs, load factor and installed capacity (size of plant), 2) the company's generation mix, and 3) the policies adding or lessening the revenue. It also results from electricity prices, which was not listed among our drivers.

Excluded variables are most of the market driver-related variables: financing methods and the HHI, but also the 'construction timescale' technical variable and nuclear policy-related variables, which is coherent with our previous assumption according to which nuclear policy is invariant over time.

One striking result of this analysis is that all variables of market driver (the HHI, financing methods and grid development)

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have no influence whatsoever on the system and are excluded variables. This does not mean that they are not important individually for the investor when it comes to making a decision, but that they do not interact with other variables in the system composed by the identified drivers. This means that given the little direct interaction the market structure has with the other decision drivers, it will not change significantly over time. The financing methods – which are part of a more general issue of industrial financing (not only energy, not only electricity) – are more related to trends in the field of finance and banking.

Another striking result is that the company drivers are mostly clustered variables: it means that they have unclear influences that our structural analysis was unable to reveal, which is one of the limits of the tool. One counter-intuitive result is to have €/MW investment costs as a clustered variable, and not an input variable like generation cost. Clustered variables' role is not easily interpreted; however this could mean that it is not the cost per MW that really makes the investment capital-intensive, but the size of the plant, and also that the load factor indicates how fast the investment will be profitable

Lastly, the quasi-absence of resultant variables shows that there is no variable that can be influenced without cascading effects on other variables. In our investment choice problem, this means that there is no parameter easy to target to obtain a clear effect: a change in a policy or a technical driver will not have a clear and direct result on another driver, except for the revenue. This is consistent with the difficulty of defining efficient policies for instance, or to foresee the effects of technical progress.

C. 4 Relevant types of scenarios

Relevant drivers to be applied when building scenarios are thus the climate policy and technical change, which leads to 4 main types of scenarios:

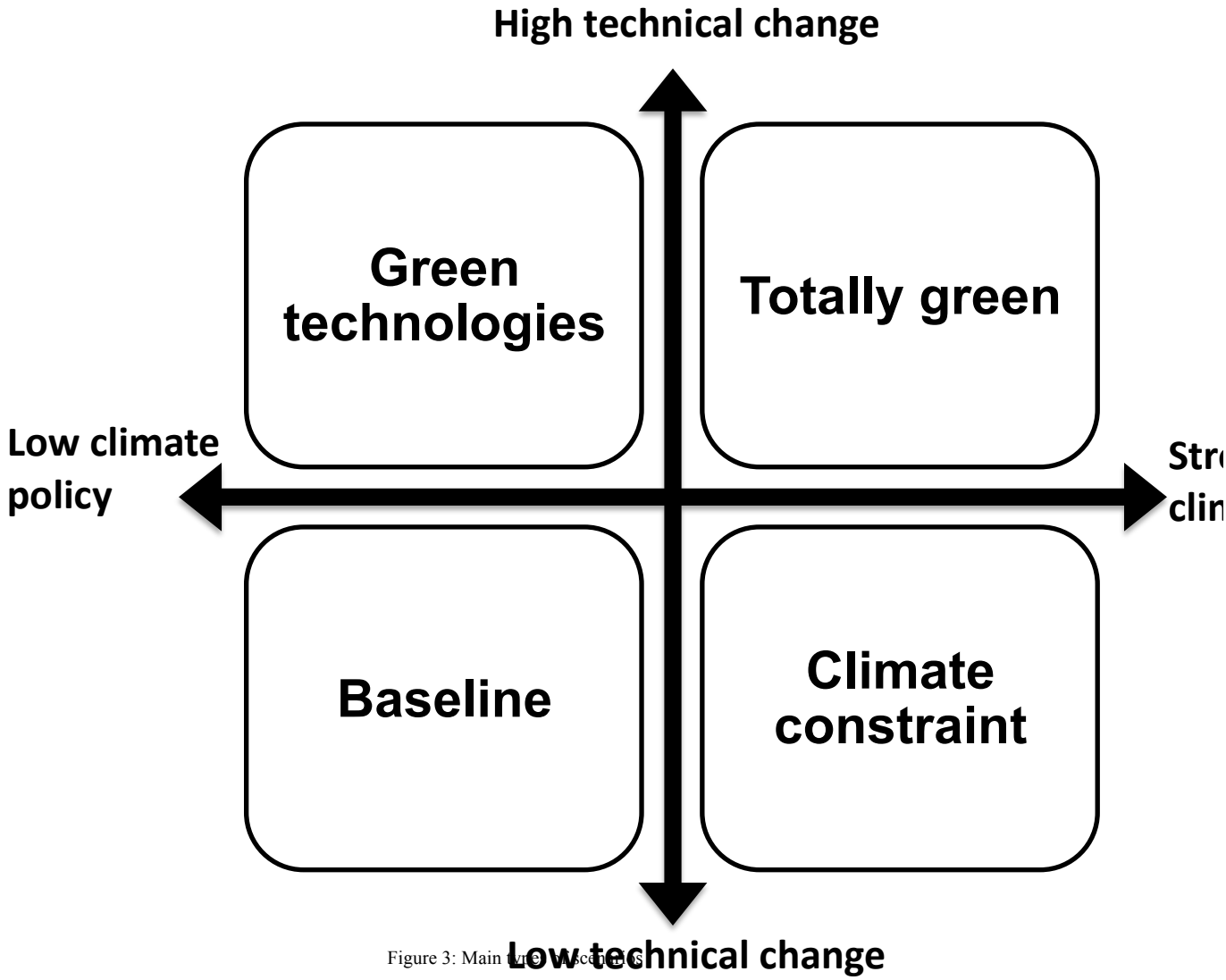

Figure 3: Main types of scenarios

In the baseline scenario, neither climate policy nor renewables know any significant upheaval. Carbon emission reduction still addressed by EU ETS market with low prices up to 4US$/ton$CO_2$, which is no strong incentive for carbon, except for UK

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who created a carbon tax that will increase as planned by the UK government. Current incentives for renewable will be pursued, some of them already being abandoned (as the solar FiT in Spain). It is the least favorable scenario to low-carbon technologies, but favorable to coal and gas. It consists in pursuing the same trends in all five countries: nuclear and fossil fuels with minor share of renewables in the UK and France, renewable and fossil fuels with minor share of renewables in Germany, Italy and Spain, meaning important carbon emissions. Fossil resources make it possible to continue using fossil-fueled electricity over the timescales considered (three decades). Nuclear development prospects will be only in France and UK (through building of EPRs), motivated by necessity of decommissioning of old plants, but the share of nuclear in their generation mix would not be likely to grow. The possibility of Fast Reactor penetration will exist in France according to French planning (Astrid project). In the end, nuclear development is supported only by pro-nuclear policies in UK and France.

The "green technologies" scenario states that renewables have achieved economic competitiveness through technical change, and there is a low climate policy. It introduces in the baseline scenario highly competitive renewables (the one predicted by the most optimistic assumptions). Since the results of the structural analysis suggest technology characteristics are the inputs for policy design, the incentives for renewables are made unnecessary by the economic competitiveness.
Like the baseline scenario, it is favorable to coal and gas investments but includes a "green" component. It is still favorable to renewables due to the technical change factor; gas investment will be promoted, since it is a low-capital, flexible technology technically suited to be a back-up capacity to renewable and economically suited to low load factors. More generally, among low-carbon technologies, this scenario tends to reduce nuclear investment in favor of gas and coal. For nuclear development, the same conclusion can be drawn, except that nuclear investments are less attractive given new competitive technologies on the market: nuclear is expected to lose market shares even in pro-nuclear countries.

The "totally green" scenarios, in which a strong climate policy is combined with high technical progress for renewables, are the most favorable to renewables and carbon emission reductions. Carbon prices will rise up to thanks to carbon tax or reform of carbon market. Renewable cost will decrease and at first be supported by strong incentives, which should attract investments. Renewables becoming competitive makes support policy useless, so the incentives should disappear at the latest after 20 years.
It is favorable to investment in both renewables and nuclear in France and the UK, and favorable to investment in renewables in Germany, Spain and Italy. In all countries, fossil-fuel-based technologies will lose market shares according to these scenarios. This means that back-up generation due to renewable intermittency will be ensured by non-intermittent hydraulic power and nuclear power. It is necessary to point out that such a situation means a lower load factor for nuclear power and thus an important loss of competitiveness on generation costs (OECD and Nuclear Energy Agency, 2012). As a consequence, such massive low-carbon investment situations would be possible only if climate policies and renewable competitiveness were strong enough to maintain nuclear investment attractive compared with fossil fuels and especially gas, or if technical change could bring solutions to intermittency such as mastering long-term storage or interconnections between numerous sources. In terms of policy, the dynamics of the 'totally green' scenario would become similar to the 'green technologies' scenario in the last decade of the considered period, except for the carbon policy that would stay stronger, and renewable penetration would be lower in the 'green technologies' than in the 'totally green' scenario since not helped by incentives. As for nuclear development, interest in nuclear would be stronger than in the baseline scenario for France and UK. It would thus make development of Fast Reactor more likely in France and encourage pending investments in the UK through the renewing of 20 GW of nuclear and potential replacing of decommissioned coal fired power plants by nuclear (up to 8,3 GW).

The "climate constraint" scenario in which a strong climate policy faces low technical change in the renewables is favorable to low carbon time-tested technologies like nuclear and hydropower. However, in the five countries studied here, hydraulic capacities are already well developed and submitted to strong environmental constraints and local opposition, which considerably limits investment in new build. Considering the nuclear policies in the different countries in question, it is thus favorable to nuclear in France and the UK. In Germany, Italy, and Spain, this scenario should be favorable to renewables through climate policy incentives and despite their limited competitiveness. This scenario thus means the use of expensive renewable energies or the use of fossil fuels combined with high carbon prices for Germany, Italy and Spain. In any case, domestic electricity generation will be achieved at high costs. Nevertheless, the artificial maintenance of technologies that have not achieved economic profitability in the long term is questionable. As the results of the structural analysis suggest, technology characteristics are the inputs for policy design. This means that within a period of 20 years (which corresponds the longest lifetime of the incentives identified), the support for renewables should decrease. A strong climate policy means that support could go to newer technologies like CCS or geothermal energy. Still, since such technologies are further from maturity than wind and solar, their penetration would not be as good as that in the 'totally green' scenarios. An alternative solution could be found in electricity imports, depending on the development of the grid, being costly itself. This scenario is the one where there is the strongest interest in nuclear energy and thus in Fast Reactors. In France, nuclear capacity would definitely be maintained and investment in FR confirmed. Nuclear investments in the UK could cover not only the renewing of 20 GW of nuclear and the replacing of 8.3 GW of coal fired power plants, but also investments to respond to increasing demand and thus gain significant

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market shares. Investment in FR could thus be considered. As for Germany, Italy and Spain, the anti-nuclear stance could be questioned.

D. 3 Scenarios for Gen IV integration

1) Identification of scenarios favorable to fast reactors

Among all types of scenarios, the "climate constraint" type of scenarios is thus the most favorable to nuclear investment and thus to FR integration. Let us clarify our point of view taking into account the neglected variables, market driver and nuclear policy: given that in the "climate constraint" context, nuclear seems the most viable solution, both moderate pro-nuclear and strong pro-nuclear stances would constitute favorable scenarios to nuclear development including FRs. In the market-related drivers, the most crucial ones are the financing methods that can, if well chosen, reduce the financial risk for investors. Market concentration factors will not be influential in this case since nuclear policy is supposed to ensure market coordination. Grid development is not an issue for centralized production means like nuclear plants.

"Totally green" scenarios are also favorable to nuclear investment, with the reserve expressed in subsection III. C. about their technical compatibility with intermittent technologies. It would need a strong pro-nuclear policy to allow for nuclear development until the stage of the next generation of reactors.

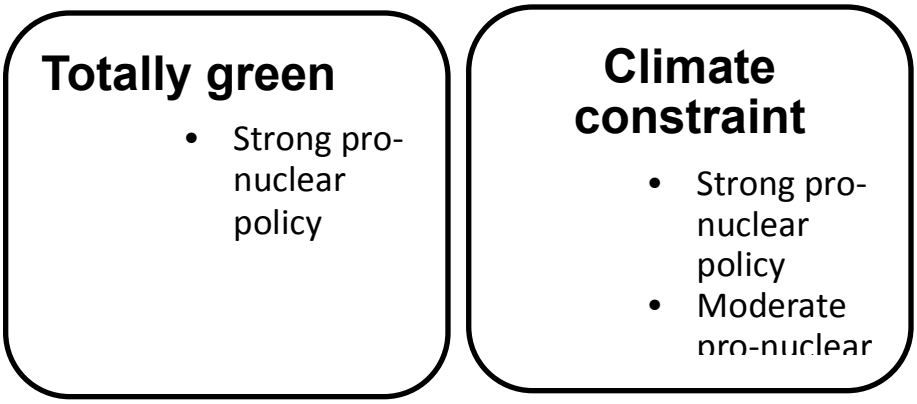

Figure 4: Three scenarios favorable to FR investments

We have thus identified the three scenarios that are the most likely to provide a favorable environment for investment in FRs. Let us not forget that these scenarios correspond to "necessary conditions" for FR development within our framework of assumption but not "sufficient conditions".

The next stage of the analysis consists in confronting the robustness of these results by observing what happens when we take the clustered variables out of the system.

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2) Further analysis without the internal decision variables of investors

In this section, we exclude the company drivers, since these variables are clustered variables for most of them. The matrix of Direct Influences and Dependences is the same as in Table I, with the 20 first lines and 20 first columns[6].

Figure 5 shows the results of the MICMAC simulation performed without these variables (20 variables instead of 26).

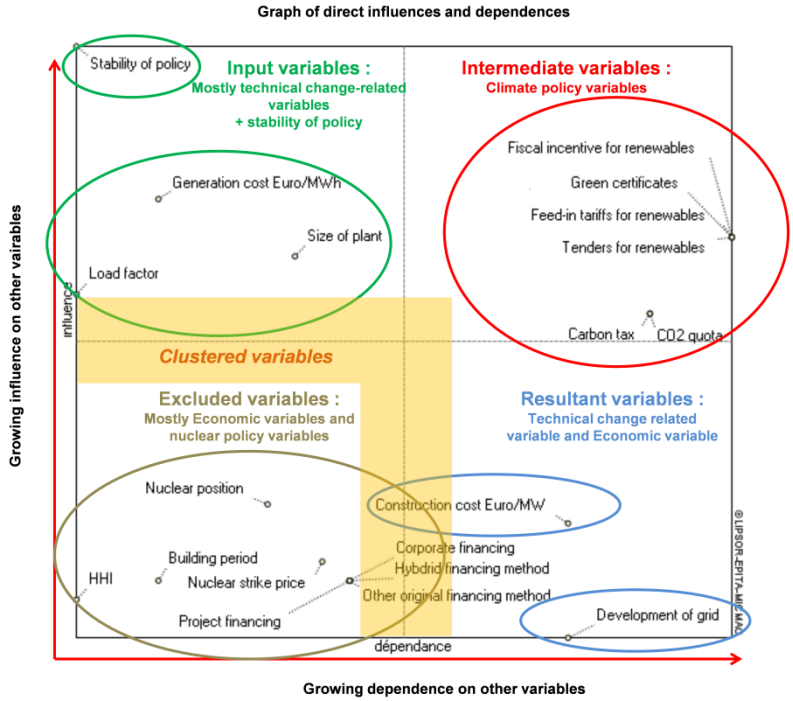

Figure 5: Chart of direct influences and dependences (external variables only)

The main tendencies of Figure 2 are clearly maintained, giving the same results regarding the relevant drivers for scenario building and confirming the robustness of the approach. However, two clustered or excluded variables appear here as resultant variables: construction costs and grid development. This means that the grid development will only be the result of policies and technology changes. Let us not that in this chart €/MW investment costs as a resultant variable, and still not an input variable like generation cost. It confirms that it is not the cost per MW that really makes the investment capital-intensive, but the size of the plant, and that the load factor indicates how fast the investment will be profitable.

V. Conclusion

This study identifies the key drivers behind the choices of investors and construction scenarios for the European generation mix based on the development of these drivers in the future: 1) policy (divided into climate policy and nuclear policy), 2) technical change and 3) market drivers. The results of structural analysis and scenario discussion show that pro-nuclear policies are not enough to promote nuclear development in Europe: business-as-usual scenarios are not favourable to FRs; climate policy appears to be the *sine qua non* condition for further nuclear development. Surprisingly, the market driver is negligible compared with the two others. In the end, both strong and moderate pro-nuclear policies are compatible with FR investment in the "climate constraint" scenarios, where nuclear is the only economically viable alternative. The "totally green" scenarios combined to a strong pro-nuclear policy assumption are also favourable to FRs in a context of flourishing renewables. Three scenarios favourable to FR investment have thus been identified regardless of the market driver; that is to say, they gather the necessary conditions for FR investments.

Climate policy changes are thus determining for nuclear investment within our European scope. On a broader scale, the climate policy of Europe is decisive for the whole international climate policy: the achievement of its objectives would be a catalyst for an international climate policy, whereas its failure would discourage further attempts to build an international

[6] The filling rate of the matrix is 22.8%, which is close to the optimal filling recommended by Godet (2001).

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climate policy. Nevertheless, this does not mean that international FR development is bound to Europe as strongly. Other drivers such as a strong electricity demand due to quick industrialization could create an environment favourable to FRs for instance in Asia, even in case of unfavourable scenarios in Europe.

There are though a few limits to be mentioned: these scenarios only combine the necessary conditions for the emergence of FRs. There is also an indirect driver "public acceptance of the technology" that is, for now, included in the nuclear policy driver. However, public rejection could appear for renewables as well because of land use and landscape transformation. Among technologies omitted in this study, carbon capture and storage could change the attractiveness of fossil fuel in the "climate constraint" and "totally green" scenarios, while the development of FRs in the form of small modular reactors could change the analysis since the market concentration factor and, above all, grid development would mostly likely become more important.

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