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## Title

# **Megaprojects as Complex Adaptive Systems:**

## **The Hinkley Point C case**

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Title

**Megaprojects as Complex Adaptive Systems: The Hinkley**

**Point C case**

Declarations of interest: None

## **Abstract**

Megaprojects are complex projects which impact millions of people, involve public and private stakeholders, and present challenges related to decision making and performance shortfalls. They are relevant cases for studying faulty management thinking as well as performance evolutions and self-organizing dynamics. Our paper builds on the theory of Complex Adaptive Systems (CAS) to understand and model processes of evolution in the Hinkley Point C nuclear power plant megaproject. The results show that CAS properties apply to megaproject changes and provide a theoretical and practical framework for examining and modeling megaproject management dynamics. We designed a research methodology combining *content analysis* and *historical research* for its relevance in conducting organizational research in conditions of complexity and non-linearity. This original research design makes it possible to conduct causal analyses of relations between key megaproject events and thus build models of evolution dynamics in stakeholder success expectations, change mechanisms in the implementation of project outputs, and self-organizing patterns.

## **Keywords**

Complexity theory, Megaprojects, Performance, Complex Adaptive Systems (CAS), self-organizing

## 1. Introduction

A megaproject costs more than 1 billion dollars, involves many private and public stakeholders and impacts millions of people (Flyvbjerg 2014). Megaproject management is an emerging field of research and the project management literature is still in search of its ‘classics’ to clearly define the scope of this new field (Flyvbjerg and Turner 2018; Pollack et al. 2018). Its impact on millions of people, its large quantities of stakeholders and its multi-dimensional ambitions make megaproject interesting object of research for studying inappropriate management thinking and lack of performance (Flyvbjerg 2014). Megaprojects are complex and evolve in unpredictable political, societal and economic environments involving hundreds of reciprocal ties (Chapman 2016). Despite the use of advanced planning techniques and risk analysis tools, modeling risk interactions and impacts on the performance of megaprojects remains a major challenge (Boateng et al. 2015), and the causes for massive cost overruns in large projects stem from the limited capacity of humans to estimate, plan or anticipate the impacts of uncertainties (Eden et al. 2005). The megaproject management (MPM) research field has to address challenges related to decision-making risks and performance shortfalls, which emerge when classical project management theories are applied to the management of megaprojects (Li et al. 2018).

In recent decades, classical project management theories, rooted in phase-project-planning methodologies and operations research (Morris 2010), have been challenged by a new project management paradigm, based on non-deterministic theories (Padalkar and Gopinath, 2016b). Recent literature on complexity and uncertainty management in projects calls for the development of a non-deterministic paradigm of Project Management based on principles of *emergence* (Daniel and Daniel 2018). Project management scholars promoted the idea that project phenomena would benefit from adapting a *complexity theory perspective* (Cooke-Davies et al. 2007; Vidal and Marle 2008) focusing on the concepts of emergence, change and non-linear feedbacks (Benbya and McKelvey 2006; Burnes 2005; Whitty and Maylor 2009), based on systems thinking (Sheffield et al. 2012) and self-organization (Saynisch 2010). However, the new paradigm based on emergence still requires more definitional clarity to move forward (Padalkar and Gopinath 2016a). Mechanisms of adaptive self-

organizations in projects are defined in theory but we know very little about how they operate because most of the research on this topic remains theoretical.

The aim of this research is to analyze and model dynamics of emergence in megaprojects, focusing on non-deterministic mechanisms of decision and implementation in megaprojects. We build on the seminal article of Anderson about complex adaptive systems (CAS) theory and its potential for understanding complexity in management and organization science (Anderson 1999), and we apply it to a megaproject case in order to verify the theoretical and practical applicability of its properties.

The research is focused on the Hinkley Point C (HPC) nuclear power plant megaproject. The project was launched in 2012 with the ambition to build a Franco-British power station, which was to be commissioned in 2018 at an estimated cost of £15 billion at the end of the front-end phase in 2016. It is a very high-profile case with organizational complexity and it has undergone performance changes during the front-end phase. The research method combines a *content analysis* of the key stakeholders' narratives and a *historical analysis* of the key events in the megaproject. We applied a historical case study method because it is a relevant research method for studying causal mechanisms of strategic processes of decision (Vaara and Lamberg 2016), and because it is particularly well adapted to conducting organizational research within non-linear conditions (Meyer et al. 2005).

In the section 2 of the paper, the literature review first clarifies the two paradigms of project management that coexist, showing that each paradigm focuses on a specific definition of project performance (*efficiency* versus *success*) and a specific project management theory (*planning and controlling* versus *modeling and adapting*). We make it clear that our research perspective examines the second project management paradigm. Then, we address the concept of dynamic complexity in project management and its impact on project managers' limited capacity to control project changes. The megaproject literature on change dynamics opens the debate of self-organizing processes and evolutions. Finally, we introduce the complex adaptive systems (CAS) theory, considered as a promising research perspective in organizations science (Anderson 1999), and we establish a link with the emerging literature on the self-organization of megaprojects. Our research assumes that CAS theory is a relevant conceptual framework for the analysis of decision-making dynamics in megaprojects. In section 3, we present the content analysis method and the historical research method

that were applied to the case of the HPC megaproject. We present the HPC megaproject case in section 4. Section 5 discusses and 6 draws conclusions about the potential of CAS theory applied to megaprojects.

## 2. Literature review

### 2.1. Two paradigms of performance in Project Management

The literature on project management distinguishes two perspectives on performance: a '*project efficiency*' perspective and a '*project success*' perspective (Cooke-Davies 2002; Serrador and Turner 2015; Turner and Zolin 2012). The '*project efficiency*' perspective is *short-term oriented* (Brady and Davies 2014) with considerations of cost and time (Bosch-Rekvelde et al. 2011), focusing on the contribution of the project to the final output during the project implementation phase. The '*project success*' perspective is *long-term oriented*, dealing with the project's contribution to the organization's outcomes and the benefits for the environment (Locatelli et al. 2016; Shenhar et al. 2001), with emphasis on strategic value (Eweje et al. 2012; Klakegg 2009), and long-term benefits (Eduardo Yamasaki Sato and de Freitas Chagas Jr 2014). Long-term performance in megaprojects is a common topic in the literature through research on corruption (Locatelli et al. 2016), project life cycle (Eduardo Yamasaki Sato and de Freitas Chagas Jr 2014), governance (Klakegg 2009), or decisions made by project managers (Eweje et al. 2012).

The Benefits Realization Management (BRM) models (BCG-PMi 2015) and the results-based development, monitoring and evaluation models (Daniel and Turner 2015; Turner 2009; Turner et al. 2010b; Xue et al. 2013) provide a framework designed to combine these two perspectives: the '*project implementation*' performance (project efficiency) consists in delivering efficient outputs, and the '*project strategy*' performance (project success) consists in delivering effective outcomes and benefits. In these project management models, project outcomes are '*new capabilities enabling the organization to achieve higher-level goals which lead to higher level performance improvement*' (Turner et al. 2010a). The Benefit Realization Management approach is a comprehensive model which considers that outputs, outcomes and benefits together influence the "*project's success*" (Serra and Kunc 2015). BRM models take a systems theory perspective on project performance (outputs, outcomes, benefits) at the strategic level (organization and environment) as well as at the operational level (project or program), but they do not really reconcile the project management perspectives presented initially (*project efficiency* versus *project success*). *Project efficiency (1)* and *project success (2)* represent two



different paradigms. The former is a well established deterministic paradigm influenced by operations research (Morris 2010; Pinto and Winch 2016) strongly related to the PMI's execution-based model, rooted in the cybernetic model of '*planning and control*'. The latter is a non-deterministic paradigm (Padalkar and Gopinath 2016b), based on Complexity Theory in projects (Crawford et al. 2006; Geraldi et al. 2011; Whitty and Maylor 2009), initiated by the Management of Projects (MoP) perspective, built on Peter Morris' research work (Pinto and Winch 2016). The rational, deterministic paradigm is the dominant approach in project management, and it historically focuses on the planning and control theories of project management (Winter et al. 2006). The non-deterministic paradigm, conceptually based on Complexity Theory (chaos theory, dissipative structures, complex adaptive systems), call for greater focus on non-linearity, instability, emergence and radical unpredictability (Cooke-Davies et al. 2007; Daniel and Daniel 2018). Systemic models applied to project management revealed that failures occur in projects because traditional methods based on determinism do not fit the actual dynamic complexity of projects influenced by inter-related causal factors and feedback loops (Cicmil et al. 2006). Some research work applied systems theories in order to understand the relations between project performance and project complexity (Antoniadis et al. 2011), but the focus was mainly on short-term performance and project efficiency. Our research clearly takes a '*project success*' perspective, focusing on the study of complex, emerging and changing relations in the megaproject between the outputs (at the operational level) and the expected megaproject outcomes/benefits (at the strategic level) in the front end-period.

## ***2.2. Structural and Dynamic complexity in project and megaproject management***

Project Management science has borrowed greatly from systems theory to analyze and describe the functioning of projects, and it has long been accepted by the community that projects operate as complex systems (Baccarini 1996; Williams 2002). The project management literature usually refers to structural complexity and dynamic complexity (Maylor et al. 2008a; Remington and Pollack 2007; Ribbers and Schoo 2002; Xia and Lee 2005). *Structural complexity* is characterized by the interdependence and diversity of components (Baccarini 1996). These components are present both at the level of the project processes and at the level of project-related business processes (Gann and

Salter 2000), which deal with the goals, the environment and players involved in the project (Antoniadis et al. 2011; Bosch-Rekvelde et al. 2011; Killen and Kjaer 2012). This article aims at clarifying the relations between the project outputs (considered as the results of project processes) and the project outcomes (considered as the results of project-related business processes). In the megaproject literature, structural complexity results from technical, organizational and environmental aspects (Chapman 2016; Lu et al. 2015).

Dynamic complexity in projects highlights the question of changes and evolutions over time, and focuses on the dynamic relations between the internal components of the project and between the project components and the environmental components (Geraldi et al. 2011). All these changes interact and create potential new changes in the project (Maylor et al. 2008b; Williams 2003). The manager's attempt to stabilize the system can actually destabilize it (Sterman 1992; Sterman 2000), and the best approach to getting the project back on track is not obvious because the strengths of the feedback loops can change during the project (Lyneis James and Ford David 2007). This article examines mechanisms of dynamic complexity, and how the changes and evolutions of project outputs and outcomes operate during the project implementation.

Megaproject dynamics reveal the emergence of new events that have impacts on project decisions and outcomes (Hertogh and Westerveld 2010). Even in the very long-term in megaprojects where each project phase may last years or decades, multiple temporalities are revealed, combining temporary and changing forms of organization (Brookes et al. 2017). The different 'moments' in the megaproject make it possible to consider the megaproject as a set of episodes or short-term events (Ruuska et al. 2011). The changes are related to the position and importance of the players involved (Aaltonen et al. 2016; Miller and Hobbs 2005) but they are also related to the evolutions in the multiple stakeholders' perspective of success (Eduardo Yamasaki Sato and de Freitas Chagas Jr 2014; Turner and Zolin 2012). This article considers the megaproject as a set of events and aims at examining the changes generated by the multiple events which are interconnected. We believe that the study of the interconnected events in the megaproject may help reveal patterns of evolutions initiated by the

various stakeholders' decisions. The systems theory perspective that we take in this research emphasizes the need to describe interactions between the stakeholder's decisions and the project outputs, outcomes and benefits.

### ***2.3. A complex adaptive systems (CAS) perspective on megaproject management***

The question of '*how dynamic complexity influences megaproject management*' is critical. Megaprojects appear to be self-organized projects where stakeholders adapt their behavior (Chapman 2016; Ruuska et al. 2011). They do this on a networks basis, as no single player involved is able to control all the rules of the project, and no external control is possible (Hertogh and Westerveld 2010). The players' behaviors follow a pattern of adaptation where each individual works with others for his/her own reasons (Aritua et al. 2009). The study of the Olkiluoto 3 and Flamanville 3 nuclear power plant projects (Ruuska et al. 2011) suggested the need to review the conventional principles of governance for large projects, and to take into account the following systems characteristics: (1) megaprojects are complex and networked structures, (2) they should emphasize self-regulation mechanisms, (3) they should be viewed as a series of short-term events embedded in a more comprehensive history and (4) they should be managed as open systems. In their approach, governance should be based on *self-organized mechanisms* where interrelations regulate the project, but no component of the network is able to regulate the whole project.

Ruuska & al. highlighted promising proposals to shift the field of megaproject management towards a better understanding of self-organization and emergence. We suggest elaborating on these findings and taking a Complexity Theory approach to examine megaproject processes as complex dynamical systems under conditions of adaptation and emergence. We believe that our research approach could provide a more operative and systematic perspective on these phenomena, with the aim of describing verifiable causal relations between outputs, outcomes and stakeholders in conditions of uncertainty and complexity. Complexity theory applied to management science is a fragmented field where complex systems theories promote deterministic models (*operational research* and *cybernetics*), stochastic models (*engineering sciences*, *science of systems*) and non-deterministic models (*self-organization*, *second-order cybernetics*) (Daniel and Daniel 2018). In his seminal article on

complexity science and organization theory, Anderson suggested that the complex adaptive system (CAS) theory would be a relevant model in organization science. He presented four characteristics of complex adaptive systems (CAS) applicable to organizations (Anderson 1999):

(1) *Agents with schemata*: Schemata are agents' cognitive structures that determine behaviors and actions. They are a set of rules that emanate from stakeholders' perception of the environment at a given point in time. Stakeholders can have different schemata and these schemata can evolve over time.

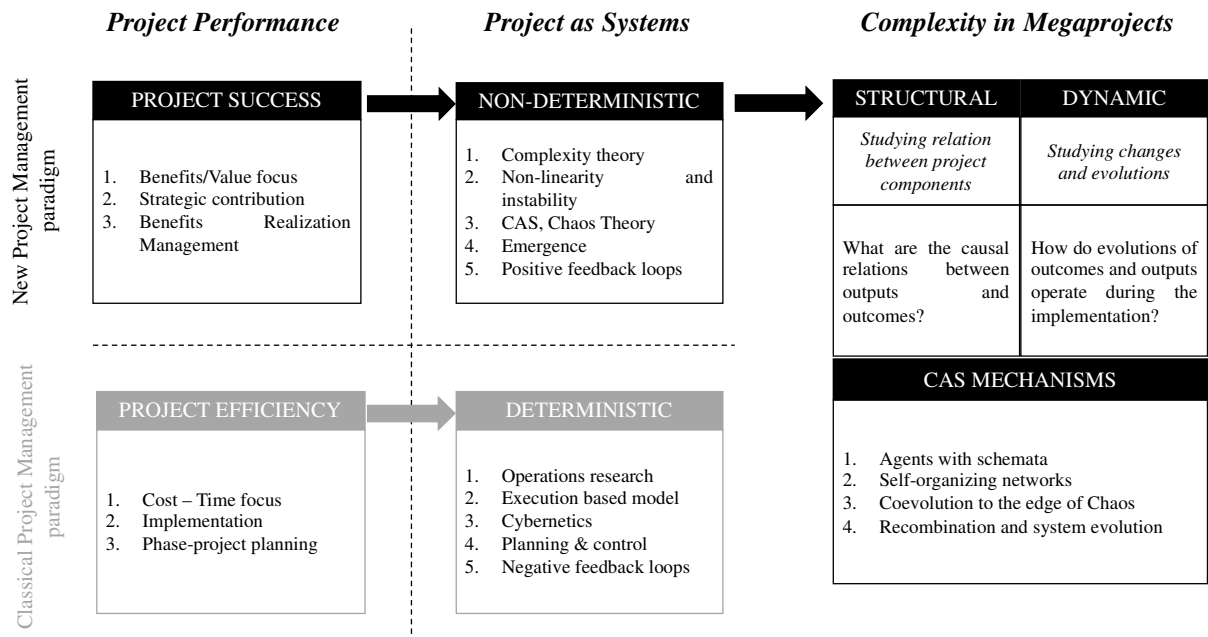
(2) *Self-organizing networks*: Stakeholders are interconnected by feedback loops. No single stakeholder dictates the collective behavior of all stakeholders;

(3) *Coevolution to the edge of Chaos*: Stakeholders coevolve with each other. The equilibrium that results from these co-evolutions is dynamic; small changes in behavior at a given time produce small, medium or large changes in the outcomes at the next point in time  $t + 1$ .

(4) *Recombination and system evolution*: The system evolves over time through the entries, exits or transformation of system components. The components or agents of the system are formed by recombining elements that could previously be successful. The link between stakeholders will evolve over time.

Despite relations that appear between CAS properties and some of the megaproject management proposals, the CAS model was only tested in the portfolio management domain (Aritua et al. 2009). We believe that the four CAS properties presented by Anderson are a promising conceptual framework for examining, describing and modeling the megaproject management dynamics of change and evolution as well as their impact on the emergence of the project's 'success'. The megaproject case study focuses on each of these four characteristics in order to reveal *operational patterns* that would go beyond the mere analogical use of CAS, and to provide a systematic and repeatable approach to self-organization mechanisms in megaprojects.

Figure 1: Literature diagram



### 3. Research aim and methods

#### 3.1. A historical case analysis

A longitudinal case study provides a theoretically sound way of examining and understanding dynamics in the context of megaprojects (Flyvbjerg 2006; Van Marrewijk et al. 2016). The megaproject selected in this research has been subject to external and internal modifications that impacted the actual performance (*project outputs*) and the expected performance (*expected outcomes or benefits*). The highly strategic dimension of the case makes it a perfect opportunity to study the complex nature of the interaction between the key decision makers' expectations (*project success*) and the actual project outputs delivered during the front end (*project efficiency*). The case offers the possibility to analyze and compare decision-making processes from two stakeholders' perspectives to examine how project complexity may impact differently (or not) both strategic processes of decision.

The contentious nature of the case involving sensitive political and commercial issues makes it very difficult to research (Smyth et al. 2017), and it makes it impossible to use conventional case study methodologies (Yin 2013). In the project management literature (Lenfle 2011), and in the management literature (Hargadon and Douglas 2001; Murmann 2013), there are similar examples of research cases that benefited from applying alternative methods based on historical analysis. Such research methods are especially fruitful for interpreting the result of decisions in past choice opportunities, and for confronting theories of organizational change with historical development (Kieser 1994).

In this research paper, project 'reality' is grasped through the analysis of real project systems, processes, outputs and changes. These mechanisms are examined using historical research methods (Morgan and Smircich 1980). We take a 'realistic history' research approach in order to better understand the conditions and causal mechanisms (Vaara and Lamberg 2016) which drive the key stakeholders' strategic decision-making. Historical research methods are particularly adapted to conduct organizational research in conditions of non-linearity where turbulent periods may usher in new epochs (Meyer et al. 2005), under conditions of complex and fast changing environments (Murmann 2013).

Our historical research approach follows the Event-Structure Analysis (ESA) method that helps build replicable and generalizable causal interpretations of events, based on an interpretative heuristics for the computer-assisted analysis of qualitative narrative sequences (Griffin 1993; Pajunen 2005). We used the ETHNO software that was specifically developed for researchers to implement Event-Structure Analysis (Corsaro and Heise 1990). First, we coded the stakeholders' facts as they described them in their narratives. Second, we built a chronology of these facts (table 2). And third, we used the ETHNO software to generate an Event Structure Analysis *graph*. Generating such a graph requires respecting the following steps:

- 1) we coded all the facts of the chronology to define 'actions';
- 2) we linked actions by answering Boolean questions proposed by the software such as 'Does B require A or a similar action?'. Answers must be Yes or NO;
- 3) the ETHNO software automatically tested the chart of actions. If any non-logical links are revealed, the software proposes some corrections to the researcher. This automatic test helps the researchers go deeper into the analysis and coding of the historical events. The researcher can do this by searching for more pieces of information in the data collected or by reconsidering the relations between actions (events), until the software approves the logical causality links;
- 4) the software validates the chart that represents the causal chain of actions.

Figure 2 presents the Event Structure Analysis *graph* in the case of the Hinkley Point C megaproject case.

### ***3.2. Data collection***

Our empirical data consists of publicly available information. We used two types of sources: *documentation* and *archival records*. All the data collected cover a specific period of time (from 2012 to 2016). Data were collected in their original language, namely French for the French part and English for the British part. Events used to build the project history were first based on press articles which were then cross-checked and deepened against official sources (table 1). On the French side, the data were drawn from the sources of the main stakeholder studied (namely EDF), supplemented by data from a key partner (namely Areva). We also gathered data from French state sources such as the

French government, the National Assembly and the Court of Auditors. On the British side, our data were drawn from the British Government represented by several of the ministries involved in the project. The data were mainly collected before the analysis. When the Event Structure Analysis *graph* was generated, additional data were collected to strengthen the coherence of the Event Structure Analysis. We considered that data collection was saturated when additional data had no effect on the coherence of the Event Structure Analysis *graph*.

Table 1 presents a detailed inventory of the types of data, their sources and the intended recipients of the data.

*Table 1: Inventory of Hinkley Point C public available data analyzed*

<b>Data type</b>	<b>Quantity</b>	<b>Original data source</b>	<b>Original (intended) data audience</b>
Hearings	6 (121 pages)	. Assemblée Nationale ( <i>French National Assembly</i> ): Economic affairs commission . Assemblée Nationale ( <i>French National Assembly</i> ): Inquiry commission on Nuclear industry cost	. National Assembly members . Ministries . General public
Discourses	1	www.vie-publique.fr official website of the direction for legal and administrative information, French Prime Minister department.	. General Public
Electronic periodical and newspapers	25	. LeFigaro.fr . LePoint.fr . LeMonde.fr . LesEchos.fr . Rfi.fr . UsineNouvelle.fr . Capital.fr . Natura-sciences.fr	. General public
Press Release	13	. Areva . EDF . UK Government: Department of Energy & Climate change . UK Government: Environment Agency . UK Government: HM Treasury . UK Government: Department for Business, Energy & Industrial Strategy	. Journalists . General Public
Information Report	2 (122 pages)	. EDF . Assemblée Nationale ( <i>French National Assembly</i> ): Economic affairs commission	. Shareholders . National Assembly members . Ministries . General public
Strategic Report	4 (803 pages)	. Cour des Comptes ( <i>French court of auditors</i> ) . UK Government: Secretary State of Investor Agreement	. Prime Minister and government . CEO of EDF . General public
Website	1	. EDF Energy	. General Public



Letter	4	. EDF . UK Government: Department for Business, Energy & Industrial Strategy	. French court of auditors . UK Government . EDF CEO
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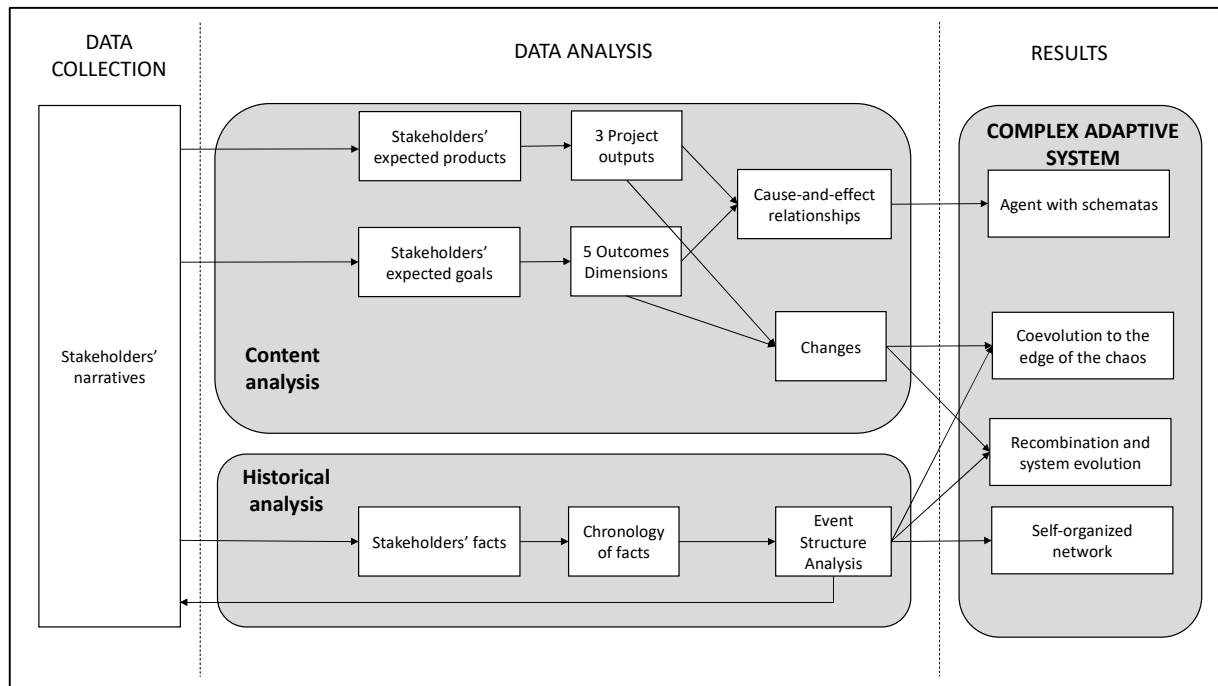
### ***3.3. Content analysis of decision makers' perceptions***

In combination with the historical analysis that we conducted, we analyzed the key stakeholders' narratives by using the qualitative data analysis program ATLAS.ti (version 1.0.50). The narratives were coded into categories compliant with the Result Based Monitoring model (Daniel and Turner 2015; Xue et al. 2013), and the Benefits Realization Management model (Serra and Kunc 2015), distinguishing the *expected outcomes* and the *real outputs* of the project. This process facilitated the distinction between the '*project success*' perspective on performance and the '*project efficiency*' perspective on performance. We then considered all pieces of narratives that referred to goals, objectives, future results, challenges and expectations as the '*project outcomes*'. After the coding process was completed, the coded data were further examined focusing on two sets of analyses: (1) the logical "cause-to-effect" relations between the 'project outcomes' category and the 'project outputs' category, (2) all the changes in each of these two categories in the front-end period of the megaproject. The "cause-to-effect" relations generated by the content analysis were considered against the 'Event Structure Analysis' *graph* generated by the historical research approach. The major changes in the project's actual and expected performance were analyzed and graphically presented. If there were any discrepancies about data from newspaper articles, the information from the official authorities or stakeholders involved was considered more reliable than information provided by external parties. Eventually, we found no contradictions between our sources: no stakeholder' narratives in a source showed any contradiction in another source.

In order to triangulate our analytical approach, two different researchers coded the various sources on the basis of a conceptual structure derived from the models (outcomes, outputs, stakeholders). Some adjustments were made to ensure that the conceptual structure was generating similar content analysis. The content analysis was facilitated by the tangible project parameters analyzed (outputs, outcomes, stakeholders) and by the application of a clear *systems oriented* model of project management.

Figure 1 presents the research methods framework that combines the content analysis and the historical analysis.

Figure 2: Research methods framework



## **4. The HPC case study**

### ***4.1. Background of the project***

#### *4.1.1. The chronology of the project*

Areva, a French company, and Siemens, a German company, developed a new nuclear technology in 1992, 6 years after the Chernobyl accident. This technology is the EPR (initially named European Pressurized Reactor, and now named Evolutionary Power Reactor). In 2016, Nuclear Power Plants with EPR were under development in Finland (Olkiluoto OL3), in France (Flamanville FL3) and in China (Taishan 3). Two of these projects, Olkiluoto and Flamanville, have been suffering significant delays (9 years for OL3 and 5 years for FL3) and huge cost overruns (4,5 billions € for OL3 and 7,2 billion € for FL3). Therefore, EDF, a French public company in charge of producing and supplying electricity (the world leader) has taken a leading position in the nuclear industry and has handled the sales and constructions of nuclear power plants on the nuclear market. Areva has become a supplier for EDF nuclear projects.

The Hinkley Point C project went through a first phase from 2008 to 2012, during which the EDF collected the authorizations of the local population to decide on the location of the site. The meeting held on 17 February 2012 between the President of the French Republic and the British Prime Minister to sign the agreements on the nuclear program marked the official launch of the project and the start of the phase which is the subject of our study and which ended on September 29, 2016. After this phase, the construction phase of the power plant was supposed to begin. But this is not in the scope of our study. Between February 17, 2012 and September 29, 2016, actions were completed on both the British and French sides. These actions are presented in Table 2.

Table 2: Chronology of facts and actions in the HPC project

<b>Date</b>	<b>Facts</b>	<b>Actions</b>
17/02/12	Nuclear Program Contract signed between the President of French Republic and the Prime Minister of the United Kingdom	UK-FR agreement
04/04/12	£1.6m for West Somerset Community College to train young people	Investment
18/05/12	Bridgewater college receives £2m for local skills development	Investment
16/07/12	HPC temporary Jetty given permission	Permits
06/08/12	European Commission states that HPC proposal fulfils objectives of Euratom treaty	European approval
11/09/12	£100m package of mitigation measures agreed with Local Authorities	Investment
31/10/12	1000 Somerset firms sign up to compete for HPC contracts	Investment
26/11/12	HPC Nuclear Site License granted	Permits
13/12/12	Regulators approve EPR nuclear reactor design for use in the UK	Permits
04/02/13	Centrica Withdrawal	Replace Centrica
13/03/13	Three main environmental permits granted by the Environment Agency	Permits
19/03/13	Secretary of State approves construction of new nuclear power station at HPC in Somerset	Permits
05/06/13	Ground-breaking industrial relations agreements for HPC project	Investment
16/10/13	Memorandum of understanding UK-China	UK-China agreement
21/10/13	Agreement on commercial terms for HPC Between UK government and EDF	Commercial agreement
05/11/13	Electrical and mechanical Trade Union agreements announced with GMB and Unite	Investment
18/12/13	European Commission announces an opening decision on HPC	European approval
10/12/13	New tensions between Areva and TVO on Finland EPR due to delays	Other projects
06/03/14	“Grand Carenage” Project is decided by the French government and supported by EDF	Other projects
07/04/14	HPC State Aid consultation completed	European approval
08/10/14	European Commission approves HPC agreements	European approval
19/11/14	Areva withdrawal	Replace Areva
23/02/15	Construction skills and Innovation Centre opens in Cannington	Preworks
20/03/15	New National College for Nuclear announced	Preworks
31/07/15	Preferred bidder companies join the team	Preworks
21/09/15	Chancellor announces £2billion Infrastructure UK guarantee	Guarantee approval

24/09/15	Further preferred bidder contracts announced	Investment
09/10/15	European Commission approves UK waste transfer contracts	European approval
21/10/15	EDF and CGN sign the Strategic Investment Agreement of HPC	Investment agreement
17/12/15	Opening of new bypass around nearby village of Cannington	Preworks
07/03/16	EDF Financial Director withdrawal	EDF approval
May 2016	French government decides to waive dividends of EDF equity	EDF approval
04/07/16	Conclusion of consultation with EDF Company Works Council	EDF approval
13/07/16	New Prime Minister appointed	New UK PM
28/07/16	EDF Board of Directors approves final Investment decision	EDF approval
31/07/16	UK new Prime minister decide to postpone her decision on HPC project	Review project
15/09/16	UK Government confirms its agreement for the construction of HPC	Review project
16/09/16	EDF accepts the agreement of the UK government	EDF agreement
29/09/16	Final Agreement signed for Hinkley Point C	Final Investment agreement

#### 4.1.2. *The Outcomes of the project*

According to ‘*project success*’, project’s outcomes are the results expected by the project’s key stakeholders after the end of the project. We analyzed expected outcomes of two of these key stakeholders: EdF and the UK Government. Table 3 presents the expected outcomes of these stakeholders at the beginning and at the end of the front-end period. The outcomes that were analyzed could be classified by stakeholder (EdF and UK Government). The content analysis reveals 5 dimensions of the stakeholders ‘expected outcomes’:

- *Economic*: expectations related to a market or industry
- *Technological*: expectations related to skills or competences
- *Political*: expectations related to relations between countries and company
- *Financial*: expectations related to financial benefits
- *Ecological*: expectations related to the Environment and the ecology

Table 3: Outcomes of Hinkley Point C megaproject

<b>OUTCOMES</b>			
<b>DIMENSIONS</b>	<b>STAKEHOLDERS</b>	<b>Start - IN 2012</b>	<b>End - IN 2016</b>
<b>ECONOMIC</b>	UK Government	To create jobs	UK companies could be entrusted with up to 60% of the work  26,000 jobs created during construction and 900 permanent jobs
	EdF	To go through market price fluctuations	To create thousands of jobs  To create 64% of benefit for UK industries  To become a leader on the low carbon market
<b>TECHNOLOGICAL</b>	UK Government	To improve nuclear safety	Power supplied to nearly 6 million homes
	EdF	To recognize its industrial expertise and key milestones in the implementation of its new nuclear strategy	To supply safe power for 7% of future needs in the UK in 2025
<b>POLITICAL</b>	UK Government	To reinforce industrial partnerships	To ensure that the full implications of foreign ownership are duly examined for the purposes of national security
	EdF	To reinforce partnerships with UK	To consolidate the presence of EdF in the UK  To not reduce EdF shares under 50% without the UK government's consent
<b>FINANCIAL</b>	UK Government	To reduce consumers' bills over long-term	To provide financial security for the next generation  Not pay a consumers' penny until the plant is up and running
	EdF	To build 4 power stations in the UK	To develop new stations in Suffolk and Essex
<b>ECOLOGICAL</b>	UK Government	To produce low carbon energy	A clean, home-grown source of electricity which will avoid by 9 million tons of CO2 per year
	EdF	To provide low carbon power	To provide low carbon power  To fight global warming



#### 4.1.3. *The Outputs of the project*

The content analysis of stakeholders' narratives revealed that the stakeholders' decisions and actions contributed to delivering three main *project outputs*, which are:

- *Investment partnerships*: the organization of investors in the project and future operations of the power station
- *Power station*: construction with the EPR technology
- *Contract for difference*: the official contract that sets the price per megawatt/hour price when the station is up and running, depending on the electricity market, the date of commissioning for the operation and the level of profitability of the project. This contract describes operating conditions and sets penalties in the event of non-compliance.

In the stakeholders' narratives, it clearly appeared that these three project outputs were contributed to the achievement of project outcomes categorized in economic, political, ecological, technological and financial dimensions. Table 3 presents stakeholders' decisions/actions related to project outputs and project outcomes.

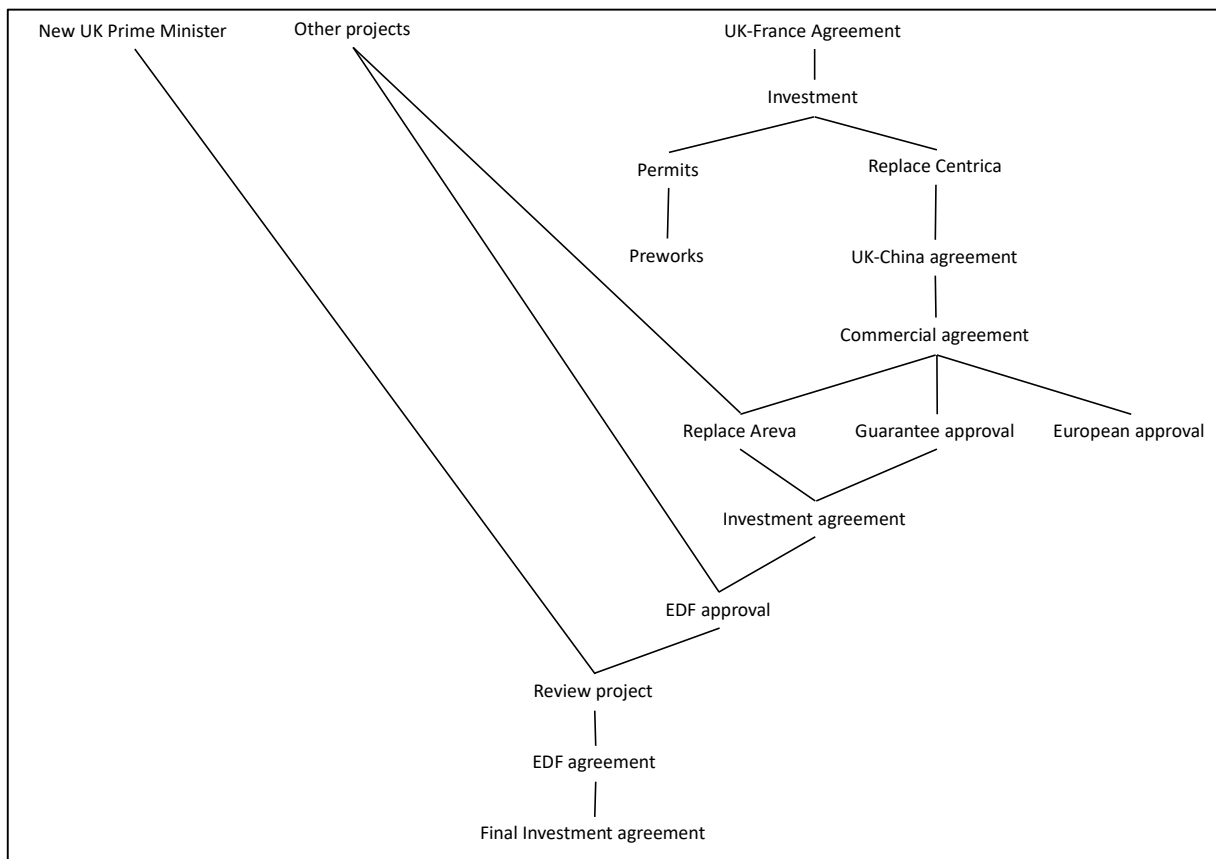
Table 4: Outputs of Hinkley Point C

PROJECT OUTPUTS	OUTCOMES DIMENSIONS	STAKEHOLDERS' ACTIONS
INVESTMENT PARTNERSHIP	Economic Technological Political	UK-FR agreement Replace Centrica UK-China agreement European approval Replace Areva Guarantee approval Investment agreement EDF approval Review project EDF agreement Final Investment agreement
POWER STATION	Economic Technological Political Financial Ecological	Investment Permits European approval Preworks
CONTRACT FOR DIFFERENCE	Economic Financial Ecological	Commercial agreement Investment agreement Review project Final investment agreement

#### 4.1.4. The Event Structure of Hinkley Point C

From 2012 to 2016, Hinkley Point C involved a chain of actions that were linked by causes-and-effects relations. Figure 2 presents the causes-and-effect relations of project actions through the Events Structure Analysis (ESA). Actions start with the “UK-France agreement” signed by the President of the French Republic and the British Prime minister; and finish with the “Final Investment Agreement” signed by EDF, CGN and the British Government. Actions like “New UK Prime Minister” and “Other projects” are *external causes* of the HPC megaproject but have *real effects* on the HPC megaproject. Figure 2 is the Event Structure Analysis *graph* that clarifies the causal relations inside the megaproject.

Figure 3: Event Structure Analysis graph of Hinkley Point C megaproject



#### 4.2. Agents with schematas

‘Agents’ may be individuals, groups or coalitions of groups. Schemata are cognitive structures that determines behaviors and actions. They are a set of rules that emanates from stakeholders’ perceptions of the environment at a time *t*. Stakeholders can have different schemata and these schemata may or may not evolve ‘(Anderson 1999, p.219).

In the project management literature, *project success* is a shared and common perception of project stakeholders (Davis 2016). Table 5 describes the results of the content analysis based on the narratives of EdF and the UK Government.

Table 5: Key stakeholders’ schemata structures and meanings

<b>Schemata structures and meanings</b>	<b>Electricité de France (EdF)</b>	<b>UK Government</b>
<b>‘Environmental orientations’</b>	<i>Economic:</i> International nuclear market <i>Technological:</i> Quality of electricity produced <i>Political:</i> EdF investments control <i>Financial:</i> Spin-off for EdF Group <i>Ecological:</i> Carbon emission reduction	<i>Economic:</i> National economy <i>Technological:</i> Quantity of electricity produced <i>Political:</i> Foreign investments control <i>Financial:</i> Spin-off for UK Consumers <i>Ecological:</i> Carbon emission reduction
<b>‘Organizational level’</b>	<i>Macro:</i> Corporate strategy <i>Meso:</i> HPC project <i>Micro:</i> Power station Contract for difference Investment partnership	<i>Macro:</i> Country policy <i>Meso:</i> HPC project <i>Micro:</i> Power station Contract for difference Investment partnership
<b>‘Individual intentions’</b>	<i>Business oriented:</i> <ol style="list-style-type: none"> <li>a) Client satisfaction</li> <li>b) Profit for the Group</li> <li>c) Optimizing cost</li> <li>d) Position on the market</li> <li>e) Skills and expertise</li> <li>f) Low carbon energy producer</li> </ol>	<i>Citizens oriented:</i> <ol style="list-style-type: none"> <li>a) UK employment</li> <li>b) UK businesses</li> <li>c) Homes receiving electricity</li> <li>d) UK security for foreign investments</li> <li>e) Next UK generation</li> <li>f) UK CO2 production</li> </ol>

Our analysis revealed two conclusions: (1) both stakeholders share the same structure of perception, based on common dimensions, (2) but each stakeholder defines his/her own expected outcomes.

***Shared structure of perception:*** Each stakeholder perceives the project and its long-term performance through three characteristics: (1) *environmental orientations*, (2) *organizational levels* and (1) *individual intentions*:

- *Environmental orientations.* They are domains of the project environment that would be impacted after the end of the project: economic, technological, political, financial and ecological.
- *Organizational levels.* Each stakeholder perceives three organizational levels of the project: micro, meso and macro. The micro level is the perception of the project as a range of outputs. The meso level is the perception of the project according to the entire organization. The macro level is the perception of the project as a part of a program or portfolio of projects in a corporate strategy or country policy.
- *Individual intentions.* These intentions are a set of interests that clarifies stakeholders' commitments to the project such as '*business oriented*' for EdF and '*citizens oriented*' for the UK Government.

***Distinct meanings of perception:*** Table 5 reveals that although the stakeholders' structure of perception is shared, their real expected outcomes may be very different:

- For '*Environmental orientations*', stakeholders share the same 5 dimensions, but their expectations have different meanings as far as economic, technological, political and financial orientations are concerned.
- For '*Organizational levels*', stakeholders share a '3-levels' structure of organization but the meaning of perception is different for the macro level.
- For '*Individual intentions*', stakeholders share the fact that they have an interest in the project, but their interests are different.

### 4.3. Self-organizing networks

*Stakeholders are interconnected by feedback loops. No single stakeholder dictates the collective behavior of all stakeholders (Anderson 1999, p.219-220).*

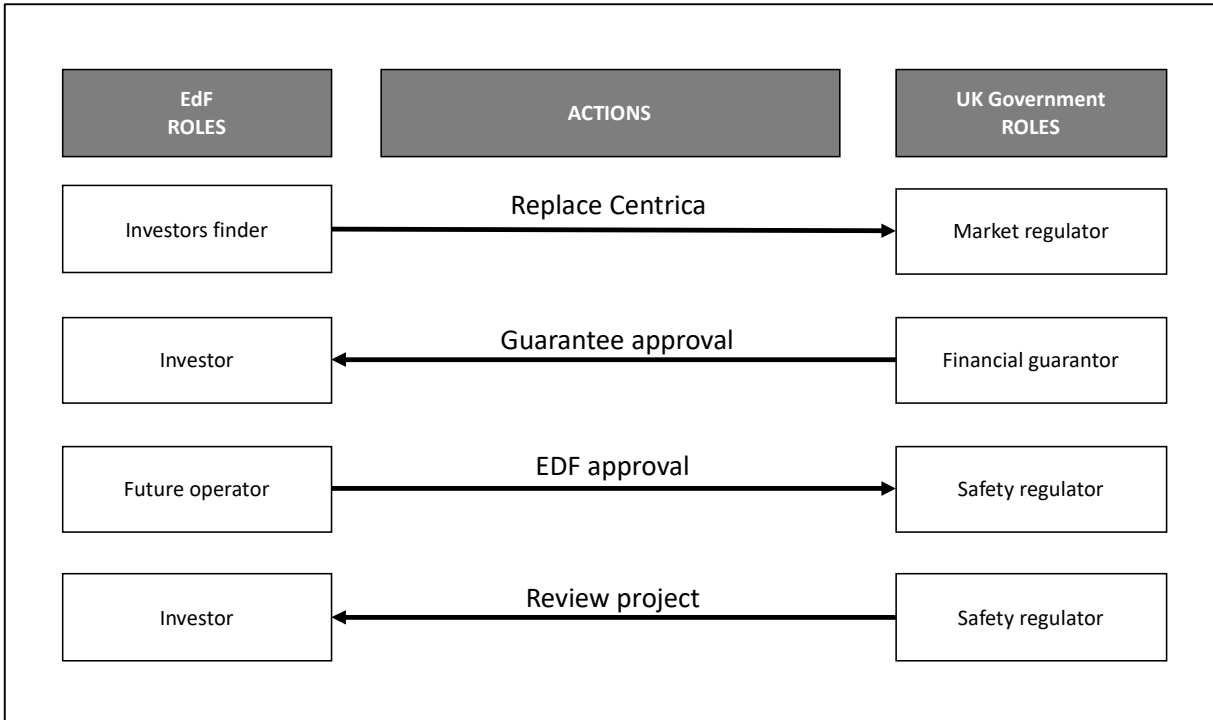
A self-organizing network is characterized by stakeholders that have a supplier role in the network and not by a hierarchical structure with principal and agent roles (Ruuska et al. 2011). Based on the Event Structure Analysis of the Historical research (figure 2), we analyzed actions where a stakeholder has an impact on the behavior of the other stakeholder.

Figure 3 presents the roles played and actions that one stakeholder in influencing the behavior of the other stakeholder:

- In the '*Replace Centrica*' action, EdF plays the role of the finder of investors. It selects Areva and CGN a Chinese company. Its decision influences the UK Government that signs a UK-China agreement on Nuclear activities.
- In the '*Guarantee approval*' action, the UK Government plays the role of market regulator by financially guaranteeing £2 billion in infrastructures for the first tranche of the project. Its decision influences EdF that signs the Investment agreement with CGN.
- In the '*EdF approval*' action, the board of EdF plays the role of future operator by approving the future operating conditions. Its decision influences the UK Government and the new Prime minister, who decides to review all the conditions of national safety decided by the former Prime minister.
- In the '*Review project*' action, the new UK Prime minister plays the role of safety regulator by changing the investment conditions for foreign investors to ensure the national safety. Her decision influences EdF, which agrees to not having less than 50% of shares without the consent of the UK Government.

Our findings reveal that influences are mutual: they go from one stakeholder to the other. No stakeholder has total control over the behavior of the other. It is not clear which one is the “principal”, and which one is the “Agent”. This two-way relation represents the feedback loops described by Anderson.

Figure 4: Mutual influences of stakeholders



#### **4.4. Coevolution to the edge of chaos**

*Stakeholders coevolve with each other. The equilibrium that results from these co-evolutions is dynamic: small changes in behavior at a time  $t$  producing small, medium or large changes in the outcomes at time  $t + 1$  (Anderson 1999, p.220).*

The co-evolution process involves at least two agents (industries, populations, stakeholders). The analytical process of co-evolution implies two steps: (1) the first step should show that agents have changed from time  $t$  to time  $t+1$ , (2) the second step is the analysis of a reciprocal causal mechanism that exists between the agents (Murmann 2013). The cause-to-effect mechanism between two agents is appropriate to analyze a co-evolutionary phenomenon.

Figure 4 presents actions extracted from the Event Structure Analysis *graph* that contribute to the evolution of EdF's outcome and the UK Government's outcome. Each stakeholder starts with his own outcome: '*to reinforce the partnership with the UK by owning 50% of the shares of the power station*' and '*to reinforce the industrial partnership with France by having a UK company as a shareholder in the project*'. At the end of the evolution process, expected outcomes are '*to consolidate presence in the UK with 66% of shares of the power station*' and '*to ensure that foreign ownership is duly examined for the national security by controlling the shares of the French and Chinese project owners*'.

The evolution of stakeholders' outcomes is the consequence of a "cause-to-effect" chain between the two stakeholders:

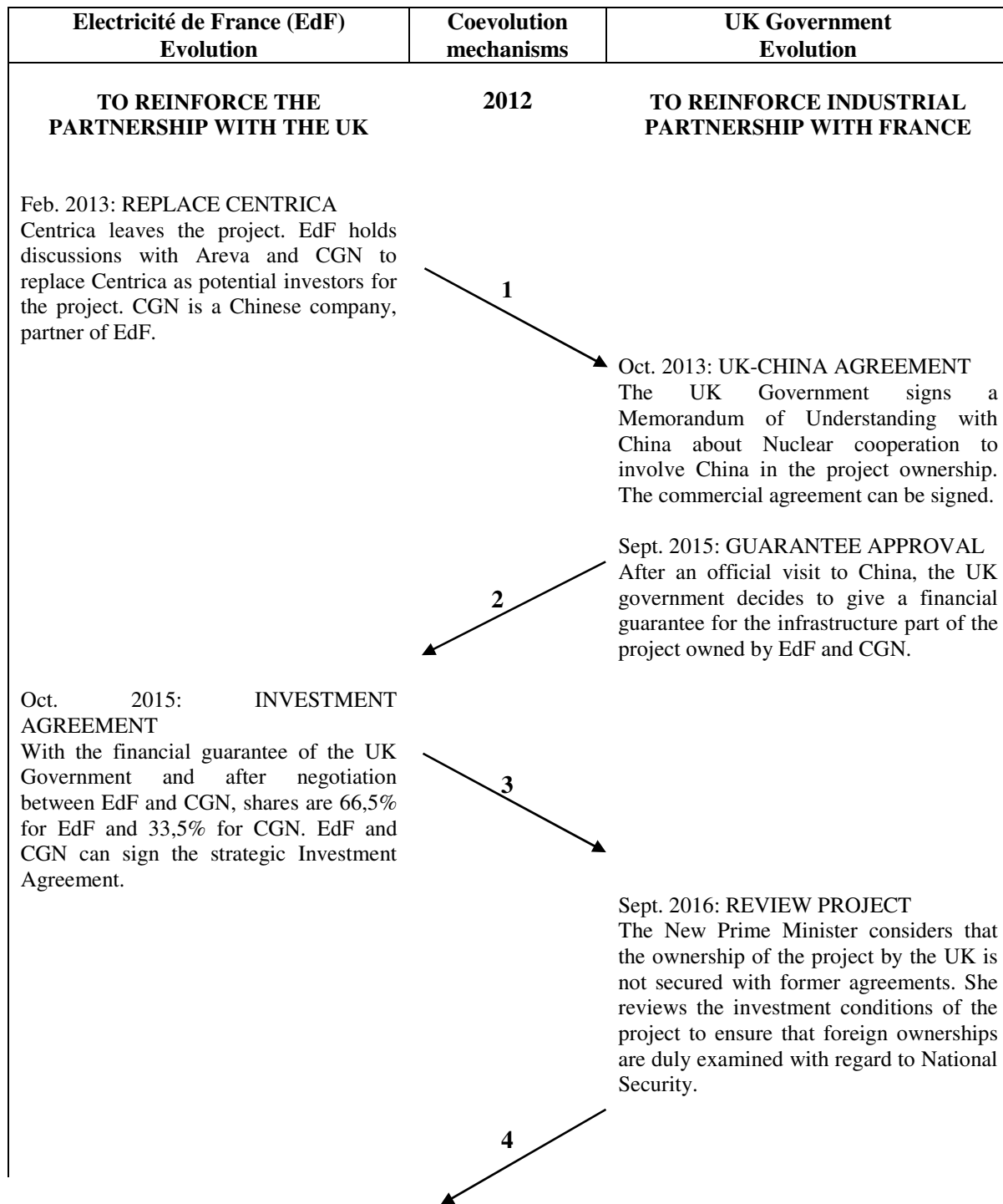
1. '*Replace Centrica*' is an EdF action that induces a UK Government action: "UK-China agreement"
2. '*Guarantee Approval*' is a UK Government action that induces an EdF action: "Investment agreement"



3. *'Investment agreement'* is an EdF action that induces a UK Government action: "Review project"
4. *'Review project'* is a UK Government action that induces an EdF action: "EDF approval"

The findings show that one stakeholder's outcome does not depend only on its choice but also on the choice of another stakeholder. The chain of cause-to-effect actions explains how an outcome at time  $t$  evolves to another outcome at time  $t+1$ . This chain of cause-and-effect and the evolution of outcomes show how stakeholders adapt to each other: their action influences the outcome of another stakeholder, who in return reacts by implementing an action that influences the initial stakeholder's outcome. Therefore, we can describe a coevolution as a chain of causes-to-effects between stakeholders that generate changes in their outcomes. Figure 4 graphically represents such a dynamic process.

Figure 5: Causal Map of Coevolutionary dynamics



Sept. 2016: EDF AGREEMENT

If EdF intends to run the project, it must agree to new conditions of the UK Government whereby it cannot sell its shares below 50% without the UK Government's consent and cannot use the guarantee for the first tranche of the project. It agrees to these new conditions in order to consolidate its presence on the UK market.

**TO CONSOLIDATE THE  
PRESENCE OF EDF IN THE UK**

**End of 2016**

**TO ENSURE THAT FOREIGN  
OWNERSHIPS ARE DULY  
EXAMINED WITH REGARD TO  
NATIONAL SECURITY**

#### **4.5. Recombination and system evolution**

*The system evolves over time through entries, exits or transformations of system components.*

*The components or agents of the system are formed by recombining elements that could be previously successful. Thus, patterns of interconnections, the strength of each connection and the links between the stakeholders will evolve over time (Anderson 1999, p.220).*

Based on the Event Structure Analysis *graph* (figure 2) we applied content analysis on actions as entries and their effects on other actions in the project:

- For entries: "Other projects" and "New UK Prime Minister"
- For effects: "Replace Areva", "Investment agreement", EDF approval", "Review project", "EDF agreement" and "Final Investment agreement"

Table 6 presents changes in output characteristics and stakeholder relations due to entries and transformations in HPC:

- **Entries** are actions that introduce a new stakeholder in the project or new information about external project;
- **Transformations in project outputs** are changes in characteristics such as profit (capital structure), schedule (date of commissioning year) and specifications (investment conditions).
- **Transformations in stakeholders' relations** are modifications of the stakeholders' roles in the context of their relations with other project stakeholders.

Our findings show that the structure of the project is reviewed in the front-end of the project. The transformations impacted the project outputs characteristics and the stakeholder relations. This transformation was induced by stakeholders' entries and information from the environment of the project.

Table 6: Recombination of Hinkley Point C project

Exits and Entries	Transformations	
	Project Outputs	Stakeholder Relations
<ul style="list-style-type: none"> <li>▪ Entry of information about other projects</li> <li>▪ Entry of new UK Prime minister</li> </ul>	<p><b><i>Investment partnership:</i></b></p> <ul style="list-style-type: none"> <li>▪ Modification of capital structure</li> <li>▪ Modification of investment conditions</li> </ul> <p><b><i>Contract for Difference:</i></b></p> <ul style="list-style-type: none"> <li>▪ Modification of commissioning year in the terms of the contract</li> </ul>	<ul style="list-style-type: none"> <li>▪ Areva becomes only co-contractor of EdF</li> <li>▪ CGN becomes co-owner with EdF</li> <li>▪ UK Government becomes guarantor for infrastructure</li> <li>▪ EdF Group becomes financial guarantor of the project</li> <li>▪ French Government becomes financial support of EdF in the project</li> </ul>

## 5. Discussion

Each of the four CAS properties presented by Anderson (Anderson 1999) – agents with schemata, self-organizing network, coevolution to the edge of chaos, recombination and system evolution - could successfully be *analyzed* and *described* in the HPC megaproject. The very conceptual properties presented in Anderson's article in 1999 can be considered as more operational in the HPC megaproject case presented. We believe that it is a first theoretical and methodological contribution to megaproject management research. Complexity theory applied to organization science frequently has to face critics because of a lack of operationality. It frequently has difficulty going beyond the metaphor. This research is an attempt to deal with this limitation, proposing a research design (*content analysis* and *historical analysis*) able to translate the theoretical concepts into more operational descriptions. Beyond the attempt to validate CAS properties in megaprojects, the research findings reveal megaproject management patterns:

### ***1. Megaproject perception of success is multidimensional***

Both narratives of EdF and the UK government revealed that their perception of project success is defined through a *common structure* built on three dimensions: *environmental* (economic, technological, political, financial, ecological), *organizational* (macro, meso, micro) and *individual* (intentions orientation). However, the comparison of the *perceptions of success* of EdF and the UK Government reveals that their expectations are not aligned. Our case confirms the findings of Turner and Zolin which show that project success is a multidimensional perception, by several stakeholders over several timeframes (Turner and Zolin 2012).

### ***2. Megaproject self-organization is based on each stakeholder's source of control***

In the HPC case, EdF controls the project resources while the UK government controls on the project rules. Consequently, each of them has a specific source of control. Our results show that the self-organization mechanism is based on these two sources of control, one being under the influence of EdF, the other being under the influence of the UK government. Each key stakeholder has real, but limited, control over the project. It confirms that the principle of self-organization is rooted in the

stakeholders' interrelations (Ruuska et al. 2011), and that the control is shared by the various players involved in the system (Boateng et al. 2015).

### ***3. Megaproject coevolution is based on stakeholders' reaction towards new deliverables***

The UK government's evolutions were a consequence of EdF's replacement of investors. In parallel, EdF's evolutions were a consequence of the UK government's modifications of investment conditions. The key changes in the megaproject follow a coevolution mechanism. This mechanism is dependent on the position of each key players (Aaltonen et al. 2016; Miller and Hobbs 2005), as all of the players involved generate constraints for the others, and force them to adapt (Chapman 2016).

### ***4. Megaproject recombination reveals transformations in outputs and stakeholder relations***

The four key transformations that appeared between 2012 and 2016 show that key project outputs appeared (creation of a memorandum of understanding), disappeared (removal of a financial entity) or were modified (change in capital structure). They also reveal that stakeholder relations were redefined (CGN becomes co-owner with EdF). These results confirm the concept of multi-temporalities in megaprojects as being temporary forms of organizing processes (Brookes et al. 2017) or episodes in the project (Ruuska et al. 2011).

The conventional project management paradigm, based on traditional management control mechanisms within the project, is rooted in the *cybernetic-control model* (Deming 1986; Shewhart 1931). Classical project management practices are based on the managers' capacity to implement processes of control that operate as *negative feedback loops* and maintain the project processes of production in the initial plan. Our results reveal that the HPC megaproject's behavior is in fact influenced by *positive feedback loops* that are sources of *emergent* outputs and outcomes. In practice, the key stakeholders' decisions and actions are influenced by new outputs not expected in the initial plan (Replace Centrica), and the key stakeholders' reactions create new outputs which contribute to amplify the modification of the initial plan (UK-China agreement). Our results suggest that positive feedback loops mechanisms play a key role in the megaproject management and its performance.

As a consequence, our results challenge the conventional project management paradigm, deeply questioning the cybernetic-control model (Deming 1986; Shewhart 1931) on the following fundamental functions:

1. ***the planning function***: We question the notion of ‘principal agent’ (Jensen and Meckling, 1976). Our results suggest that no agent is able to define alone a megaproject vision (goals and objectives), and the related actions to be planned. On the contrary, we find that each agent holds a partial and limited vision of the megaproject, that may be sufficiently effective to drive his/her own actions, but not enough to drive those of other agents.
2. ***the control function***: Similarly, we find that no ‘principal agent’ is able to exercise full control over the project trajectory efficiently, based on his/her own plan. Instead, each agent has a partial and limited capacity to influence and control the project trajectory, and consequently to modify it. The project performance (outputs and outcomes achieved) results from the combination of control capacities of key agents of the megaproject. Our results open up the discussion on a project management ‘control function’ that is shared by various agents.
3. ***the Project Management conditions of stability***: we find that megaproject management cycles do not follow a classic ‘Plan-Do-Check-Act’ loop. PDCA (known as the Deming wheel) is fundamentally based on a quasi-cybernetic loop of control, which aims at maintaining the project performance (outputs and outcomes achieved) in conformity with the plan. Our results open up the discussion on a project management process that would adapt its planning and control functions, based on new conditions linked to emerging outputs and outcomes. Moreover, we find that this project management process of adaptation is not in the hands of a ‘principal agent’, but is the result of collaborative interactions, which may be voluntary or involuntary.

In the following table, we propose a revision of the classic project management model in conditions of complexity.

Table 7: From CAS theory to a revised Project Management model

Results from the CAS theory	Towards a revised Project Management Model	Project management new issues
<p><b>Agents with Schemata</b>  <i>Megaproject perception of success is multidimensional.</i></p>	<p><b>SHARED PLANNING</b>  <i>The project performance (outputs and outcomes achieved) is a result of shared (partial and limited) agents' visions and goals. The planning function of the project is not in the hands of a principal agent only.</i></p>	<p><b>Structural perspective</b>                      The planning and control functions are 'shared' (partial and limited) by the project agents.</p>
<p><b>Self-organizing networks</b>  <i>Megaproject self-organization is based on each stakeholder's source of control.</i></p>	<p><b>SHARED CONTROL</b>  <i>The project performance (outputs and outcomes achieved) is a result of shared (partial and limited) agents' capacity to control the outputs during project implementation. The control function of the project is not in the hands of a principal agent only.</i></p>	<p><b>Dynamic perspective</b>                      The planning and control functions are adapted by the project agents as a result of (in)voluntary collaborative interactions</p>
<p><b>Coevolution to the edge of chaos</b>  <i>Megaproject coevolution is based on stakeholders' reactions towards new deliverables.</i></p>	<p><b>COLLABORATIVE ADAPTATION OF PLANNING</b>  <i>The project agents adapt their project goals because of other agents producing unexpected outputs. This has a direct impact on their planning function of project. The process of adaptation is a result of a collaborative interaction of agents.</i></p>	<p><b>Dynamic perspective</b>                      The planning and control functions are adapted by the project agents as a result of (in)voluntary collaborative interactions</p>
<p><b>Recombination and system evolution</b>  <i>Megaproject recombination reveals transformations in the outputs achieved and in the stakeholders' relations and roles in the project.</i></p>	<p><b>COLLABORATIVE ADAPTATION OF CONTROL</b>  <i>The project agents make decisions of adaptation resulting in modifications of their roles and actions. This has a direct impact on the control function of the project. This process of adaptation is a result of (in)voluntary collaboration.</i></p>	<p><b>Dynamic perspective</b>                      The planning and control functions are adapted by the project agents as a result of (in)voluntary collaborative interactions</p>



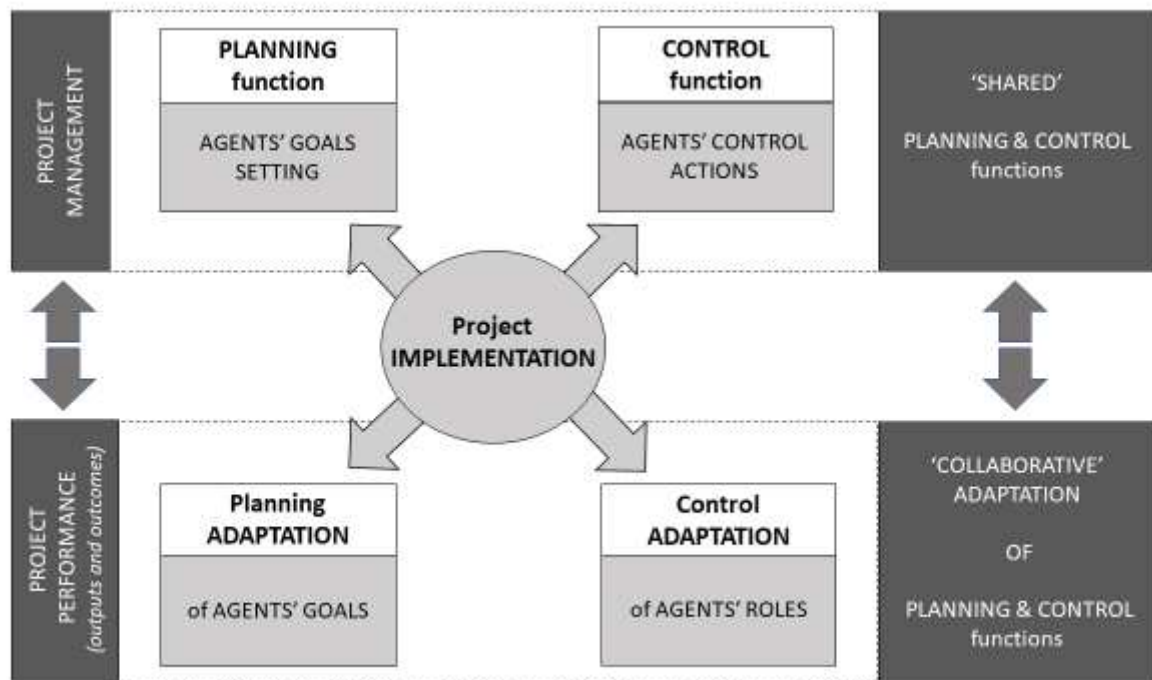
## 6. Conclusion

The conventional Project Management paradigm applied to megaprojects creates lack of long-term performance (Morris 2010). A non-deterministic approach based on the complexity theory and the emergence principle can give a new perspective to understand the mechanisms of change in implementation of megaprojects, and its impact on the project's success. The Complex Adaptive Systems theory (Anderson 1999) is a conceptual framework that helps analyze the mechanism of emergence in organizations.

This paper offers three contributions. The first contribution is to enrich the megaproject management field of research through the application of the Complex Adaptive System theory as a conceptual framework to describe complexity in megaprojects. The second contribution is to propose a theory of emergence in project management that would go beyond mere analogy, which meets actual expectations in the project management field (Padalkar and Gopinath 2016b). To do so, we provide models in order to represent patterns of complexity in projects. The third contribution is to propose to practitioners a case study questioning the classical '*planning and control*' paradigm of project management, suggesting that control can no longer be in the hands of a single player, but that it is the result of multiple agents, under conditions of self-organization and coevolution.

In terms of managerial implications, our findings highlight the necessity to revise the conventional project management model, emphasizing the strategic role of collaborative planning and control, in a project management process that is built on adaptation. The following figure shows that the project management functions interact with the project performance during implementation, following a dynamic process of adaptation generated by all the key megaproject agents.

Figure 6: Revised Project Management model based on Complex Adaptive Systems



But there are some methodological limitations in this study. Firstly, this study on one megaproject was conducted in two specific national contexts, France’s power industry and EdF on the one hand and the UK’s power industry and the UK government on the other. Thus, readers should be cautious when extrapolating the findings to different cultural contexts. Secondly, (Anderson, 1999) suggests that ‘Agents might be individuals, groups or coalitions of groups’. This study focused on only two agents that represent two key organizations in the HPC megaproject. We considered these organizations as a unified group of individuals. Our research perspective does not take into account the multiple behaviors and interpretations that could exist in each of these organizations. And third, this study is based on public and official narratives of two agents: EdF and the UK government. Consequently, our analyses are solely based on official statements that can only partly explain the intentions and perceptions of players.

Our research reveals that the project management functions of planning and control in megaprojects are not in the hands of one principal agent only. We believe that future research should focus on

understanding the advantages, constraints and limitations of collaborative planning and control in megaprojects.

The CAS theory helps to describe the dynamics of instability that operate in megaprojects, but it does not provide clear results on the ‘planning and control’ functions that should be applied in conditions of project instability and emergence. Future research should study the role and impact of techniques and methods promoting shared goals and collaborative actions of control. Future research would benefit from establishing the impacts of such project management practices on the project trajectory, and more specifically on the emergence of the project performance (the outputs and the outcomes achieved).

In recent years, there has been a growing scientific and societal interest for grand challenges (e.g. climate change, global health, sustainable cities, justice and equality, transformative technology). We believe that such grand challenges are strongly dependent on the performance of megaprojects and on our human capacity to understand how collaboration can support project management teams in coping with emergence and instability.

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