MINDFUL ANTICIPATION

a practice approach to the study of emergent technologies

Carla Alvial Palavicino

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The funding for this thesis was provided by NanoNextNL, under the section 1C. Risk and Technology Assessment

The thesis was printer with financial support from the Graduate School of Science, Technology and Modern Culture (WTMC), and the Department of Science, Technology and Policy Studies (STePS) of the University of Twente.

Cover design and layout: Stephen Sinclair & Carla Alvial Palavicino

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Printing: Gildeprint Enschede
ISBN: 978-90-365-4060-5
DOI: 10.3990/1.9789036540605
http://dx.doi.org/10.3990/1.9789036540605

MINDFUL ANTICIPATION

A PRACTICE APPROACH TO THE STUDY OF EXPECTATIONS IN EMERGING TECHNOLOGIES

DISSERTATION

to obtain the degree of doctor at the University of Twente, on the authority of the Rector Magnificus, Prof. dr. H. Brinksma, on account of the decision of the graduation committee, to be publicly defended on Thursday, 25th of February, 2016 at 14:45.

by

Carla Alvial Palavicino
born on Nov. 4, 1982 in
Rancagua, Chile

This dissertation has been approved by:

Supervisor: Prof. dr. Stefan Kuhlmann, University of Twente

Co-supervisors: Dr. Kornelia E. Konrad, University of Twente

Dr. Annalisa Pelizza, University of Twente

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Acknowledgements

It was never in the plans to write a book – but here it is, with its shiny Godzilla cover. It was also not in the plans to do a PhD, but it happened, and I learned much more than what I thought I would. I actually realized that during the last month of my PhD, when a friend asked me to give a talk for Masters students; and reflecting on my own experiences, I realized how much I have been transformed – for good, I hope – throughout this whole experience! (For the record, it is still not in the plans to do another PhD! Or write another book... but who knows! Maybe a cookbook.)

Just before sending this to publish, I write with joy some words to thank those who helped me through these dark years in Enschede, (or Enschedeath, as coined by my sister during one visit.) First and foremost, nothing would have been possible with the help of my promotors and supervisors: Kornelia Konrad, Stefan Kuhlmann and Annalisa Pelizza. I am in indebted to Kornelia for her help, wisdom and patience in a not-so-smooth learning process. Thank you for guiding me while at the same time allowing me to find my "own way" of being a researcher; be sure that you have given much more than you imagine. To Stefan, thank you for your support and patience in my learning process, more than just a researcher, as a person. Thank you both for being open to deal with some small cultural differences that enriched our experience! Last, thank you Annalisa for coming in the end of the thesis and helping me so nicely to go through the hardest part... you have the most zen approach to corrections that I've experienced so far ;)!

I would also like to thank NanoNextNL for making this research possible through the 1C: Risk & Technology Assessment, together with all the meetings, networks of researchers and activities that allowed me to take this thesis all the way. Thanks especially to the project leader Harro van Lente, for leading this project to a good end.

I would also like to give thanks for the privilege of participating of the graduate school of Science, Technology and Modern Culture (WTMC). I have to say with pride that from not understanding anything at all during the initial workshop, I left understanding at least 50% ;)!! And this is thanks to the amazing teaching skills of Teun, Willem, Bernike and Govert. Also, to the friends I met during these workshops: Colette Bos, Andreas Mitschzke, Koen Beumer, who share more than papers and thoughts with me at some point. Special mention to Wolfgang Kaltenbrunner for being the fourth unofficial supervisor of my thesis (and papers, and much more!) this work is also yours!

Being part of the S.NET community also allowed me to increase the quality and visibility of my research. Thanks in particular to Christoph Schneider, Rodrigo Cortéz, Paulo Fonseca, Pankaj Sehksaria, Trust Saidi, Poonam Pandey, who showed me that emerging technologies are not only in the industry, and not only in the global North!

I'd like to thank EU-Spri for allowing me a short stay in the Université Paris-Est, and Prof. Joly for receiving me. This was a great opportunity to reflect on the findings of my thesis and finalize it, while eating too much cheese and developing my baking skills! Thanks especially to my office-mates Tupac, Fanny and Silvère, and all the Ephemères family at LISIS.

I'd like to thank Sebastián Ureta and Tomás Ariztía at NUMIES, for giving me some time to finish my thesis while working, and to Moni, Jorgi and Caro for keeping up with my last-month-of-writing grumpiness.

This thesis is about emerging technologies, and without access to the labs, industries, conferences and meetings where these technologies take shape it would have not been possible. Thank you to people in the Graphene community, particularly the Graphene Flagship and the Graphene Stakeholders Association for allowing me in. Thanks also to Ultimaker, Printr, 3DHubs, and many others, for allowing me to be part of the 3D printing revolution ;)

I am grateful for being part of StePS. I'd like to thank Arie Rip for his constant inspiration and guidance, Lisa Roberts for her support and long-term perspective (in life!), Peter Stegmeier for staying until 9 pm and sharing some late night research thoughts, Gonzalo Ordoñez-Matamorros for his support and charisma. I am immensely grateful for the help of Marjatta Kemppainen, who always gave me financial and logistic support, in addition to her Finnish kindness that made me feel like home. To Hilde Meijer and Evelien Rietberg, I will miss our talks about life – or the weather, or future trips!; thank you for always finding time to answer my innumerable requests and coping with my inability to read Dutch! I hope to meet you again in some sunny part of the world!

I would also like to thank my colleagues and friends: Haico Te Kulve, Katrin, Verena, Sabrina Sauer, Lise Bitsch, Alejandro Balanzo, Andreas Weber. Special mention to those who made me feel at home, in their dutchness: Ivo Maathuis and Tjerk Timan, you both showed me that one can be awkward and direct while super kind and welcoming at the same time :D ! To Jun Wen Luo, for always allowing me to share some nostalgia for the East and making me dream of Asia even in the office! To Joppe van Driel, for your friendship and, of course, your hosteling services ;). María Alejandra y Andrés, for opening their hearts to a stranger also from the south.

To my friends, old and new, from NL or elsewhere, and to all the technologies that kept us connected. To those who shared with me the hurdles of lack of sun: Victoria Marín, Arturo Balderas, Leo y Loreto (y Blanquita y Pelusa), Nico Rivas, Nico Franke, Vale y Sergio, Ciro. To those who shared with me the house of Olieslagweg: Irene van de Beld, Francesca Rivello, Gianluca Tanzani, Rafael Bennertz, Lulu Tian, Lissy la Paix. To my yoga friends, teachers and students, who made this journey possible by keeping my mind clear: Anna Ravkin, Maya, Tanja, Claudia Pradella, Susanne Klappe, Katiza Satya, Rafaella, Kaisa. A special thanks to Raul Aliaga, I hope Dr. van Rainbows approves my thesis! To those friends, from far, that never forgot I was somewhere else: Coca, Magda, Vero, Mori, Nico, Felipe and their numerous postcards and packages that came from across the ocean.

I am endlessly indebted to my paranymphs, for being the friends they are in their own particular ways. Bart Walhout, thank you for sharing the joys and despairs of a PhD – in the end, it's over! I'd always keep with myself your support and your faith, and I hope you get some time sooner or later for holidays in the South of the world. To Macarena Marín, for supporting me even if I didn't listen to your advice of not doing a PhD in sun-less Europe (el sol! el sol!) thank you for being always there – in Munich – and for sharing all important moments with me, which I hope are many more.

To the most unexpected person, who came at the busiest and one of the hardest times of my life, and turned it into infinite happiness. Steve, flaco – the most mindful of all! – thank you for being here, today, for not asking neither expecting, for being true.

I'd like to specially thank my family: Berro, Oso, Lochio and Don Gordo, and to WhatsApp for allowing instant international messaging. Thank you for allowing me to be a nomad, and a dreamer, a bit of a drifted person; for believing in me more than my fears, and for making everything – not only this thesis – possible.

1. Mindful Anticipation: how the future is shaped through the active engagement with the present

Any sufficiently advanced technology is indistinguishable from magic.

Arthur C. Clarke's Third Law (1973)

Watching these popular therapists operate, often performing miracles using the honorable tricks of a skilled magician, I came up with the notion of the "sacred trap." For the extraordinary to occur, it is necessary for the sick to firmly believe in the possibility of a cure and to accept the existence of miracles. To be successful, the healer is forced to employ tricks during the first meetings, which convince her clients that material reality obeys that of the spirit. Once the sacred trap tricks the person seeking consultation, he experiences an interior transformation that permits him to capture the world by way of intuition rather than by reason. This is the only way that a true miracle can take place.

Alejandro Jodoroswky (2010),
Psychomagic: The Transformative Power of Shamanic Psychotherapy (Prologue, viii)

1.1. Introduction

The future is, for the most past, opaque and unpredictable. However, there are individuals who nevertheless profess in attempting to know and master the future, for example healers, magicians and fortuneteller. Yet even for them, the future cannot be known upfront. Instead, it is constructed through actions of social actors in the present. As in the introductory quote, this is not just any action: as in case of the "sacred trap," there are specific forms through which actors engage with the future, in which they can share and shape expectations, and make these constructed futures performative. This is the only way the "miracle" can happen (Lévi-Strauss, 1949).

As with miracles, technological development is also guided by specific future-oriented practices. In the imagination of technology actors and the broader society, these new technologies are able to perform "magic": they create wealth beyond comparison and solve many, if not all, problems of humanity. At the same time, the same technologies are potential sources of big risks and big catastrophes. These expectations, oscillating between hope and fear, between utopia and dystopia, play a central role in shaping technology futures, and consequently in shaping the future of the societies in which they are embedded (Brown & Michael, 2003).

Producing and sharing expectations is not just a matter of voicing them in the right context. The process of making expectations collective and potentially performative is enabled and mediated by specific practices. As Alan Kay puts it, "the best way to predict the future is to invent it" (1971). The production of performative promises, visions and expectations is not predetermined; instead, it is achieved through "doing" futures, the active engagement in material practices that shape, mobilize and change expectations (Michael, 2000).

While practices of future-making are not new (e.g. forecast methodologies date back to the 1950s), scholarly literature on these practices and the way in which expectations about the future are produced is overall not very extensive (Reichmann, 2013). Recent studies have focused on the "history of the future," tracing the origins and evolution of methodologies aimed at knowing and controlling the future, such as forecast and foresight (Andersson & Rindzeviciute, 2015). The emergence of specialized methodologies and organizations dedicated to managing the future, from the RAND Corporation to the Gartner group, is a reflection of the importance that these practices play in shaping politics, markets and society.

The Sociology of Expectations is a branch of Science and Technology Studies (STS) that has empirically explored the increasing role of the future in technology development. It has extensively studied the role of expectations in innovation processes, particularly for new and emergent technologies. It has shown that these expectations act as a framework for action in contexts of high uncertainty (van Lente, 1993), in which they fulfill certain functions: guidance, sense-making, coordination and legitimation (Borup, Brown, Konrad, & Van Lente, 2006; Swanson & Ramiller, 1997). As a matter of fact, expectations are performative, in the sense that both expectations, as a discourse, theories and models about the world, and the world itself, co-constitute, mutually adapt to, and evolve with each other. Expectations play a central role in anticipating new technologies. By anticipation I refer to the practices of knowing, enacting and acting upon the future through which the present is transformed and ultimately governed in the name of the future (Adams, Murphy, & Clarke, 2009; Anderson, 2010; Rip, 2012).

I have called this thesis "mindful anticipation", as its central concern is how the future of emerging technologies is anticipated and constituted through practices. At first, "mindful anticipation" might seem like an oxymoron; however, I would argue that in fact the term "mindful" embodies three core aspects discussed throughout this thesis: practice, temporality and space. In general, mindfulness refers to being actively aware of the present[1]; it means paying attention to how reality is constructed in the present time and in the current space. It also includes considering that past and future projections of reality only exist in the present. Last, mindfulness is a practice in and of itself; it is the active attention to the present. Thus, "mindful anticipation" refers to an approach in which I study the future by paying careful attention to the present, and its own ways of temporally and spatially shaping future possibilities.

In particular, I study and compare the anticipatory practices that constitute two emergent fields: graphene and 3D printing, and how these practices explain the performative effect of expectations. These two technologies, which have begun to attract general attention around mid-2000s, have gone through a phase of enthusiasm and exaggerated promises often referred to as hype. I study how these two hypes are configured across different spaces, from academia to policy circles, and from start-up companies to the world of finance. I focus on local practices and their global effects, thereby I understand expectation dynamics both as the result of situated practices but also as an aggregated phenomenon. My main research question is the following:

> What kind of practices shape processes of anticipation in emergent technologies, and what are their performative effects?

The contribution of this thesis is threefold: firstly, I develop an analytical framework to study anticipatory practices and their effects, following the terminology introduced by Anderson (2007, 2010). Secondly, using this framework I empirically study the emergence of two technology fields (graphene and 3D printing) and how future oriented practices define them. Lastly, I reflect on the multiplicity of methodologies, actors, practices and contexts in which the future of a technology is developed, providing a reflection on what it means to engage in responsible, or mindful, anticipation.

1.2. A tale of two emerging technologies: graphene and 3D printing.

The empirical focus of this thesis is on the anticipatory practices that are involved in the current hypes surrounding two emerging technologies, graphene and 3D printing. These two technologies make for an interesting comparison, because they represent distinct forms of doing innovation that emerge from different techno-economic and institutional

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1 According to the Merrian-Webster dictionary.

contexts. These are, respectively, the *regime of economics of techno-scientific promises* and the *regime of collective experimentation*. These different forms of doing innovation can be called "regimes" because they represent different configurations of rules, institutions and practices (Felt & Wynne, 2007). In each of these regimes, the narratives, temporality, forms of engagement and the ability (how and by whom) to shape the future vary. I will now illustrate this point more clearly with examples from each case.

Graphene is a two-dimensional carbon-based material that has attracted enormous attention from the scientific and technological community since its discovery in 2004 (Shapira, Youtie, & Arora, 2012). Among the multiple "achievements" of graphene is the Nobel Prize in Physics that was awarded to its inventors Andre Geim and Konstantin Novoselov in 2010. Secondly, in 2013 the FET Program of the European Commission granted 1 billion euros to a research consortium of European scientists and industries, in order to develop the social and economic potential of graphene and related 2D materials. This consortium is known as the Graphene Flagship. In a 2013 interview aimed at introducing this project, held with the former director of DG Connect Nelly Kroes, she asks Jari Kinaret, the director of the flagship, to predict the impact of graphene on European society.[2] To answer this question, he defers to the authority of Kroemer's lemma, which states that,

> The principal applications of any sufficiently new and innovative technology always have been–and will continue to be–applications created by that technology.[3]

He does not make specific predictions but instead refers to a shared notion of technological progress. However, he claims that graphene will have an impact in various areas of application, from electronics to medicine. By doing so, he makes explicit a contradiction: the future is unknown and unknowable, however, we must nonetheless act in relation to this future. Later, in a Nature editorial and in response to questions about the feasibility of the Flagship itself, he reaffirms this seemingly paradoxical perspective: "we should take graphene for granted," he says, as we have taken for granted other material innovations such as polymers, semiconductor and ceramics (Peplow 2013: pg.327). Kinaret represents a way of thinking about the future that is common to the graphene actors: a "naturalization" of technological progress, in which scientific research provides the answers to society's problems by associating technological progress to a natural process. Yet, the future remains open and uncertain. This enthusiasm does not need to be justified, but needs to be acted upon with urgency, in order to capture the opportunities the new technology provides.

3D printing has also attracted the attention of both public and private actors. The technology itself is characterized by the additive production (layer by layer) of customizable 3D

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2 https://www.youtube.com/watch?v=YY2B-13pbAw

3 Kroemer, H., 2001. Nobel lecture: quasielectric fields and band offsets: teaching electrons new tricks. Reviews of modern physics, 73(3), p.783. Emphasis in the original. (Kroemer, 2001)

objects. Formally known as Rapid Prototyping or Additive Manufacturing, this technology has been used for the development of prototypes for industrial production for more than 30 years. The more recent development of the first desktop-sized or consumer 3D printer, however, brought this technology to the general public, opening up new markets and domains of application. It has captured the imagination of the public through narratives of emancipation, autonomy and self-sufficiency, mainly related to the RepRap project (Bowyer, 2007; Randerson, 2006).[4] This is nicely exemplified by an excerpt of a science fiction story, written by Cory Doctorow in 2006 for Nature's section Futures.

> I squeezed my hands into fists so tight my fingernails cut into my palms. I closed my eyes. "You've been in prison for ten years, Da. Ten. Years. You're going to risk another ten years to print out more blenders and pharma, more laptops and designer hats?" He grinned. "I'm not stupid, Lanie. I've learned my lesson. There's no hat or laptop that's worth going to jail for. I'm not going to print none of that rubbish, never again." He had a cup of tea, and he drank it now like it was whisky, a sip and then a long, satisfied exhalation. He closed his eyes and leaned back in his chair. "Come here, Lanie, let me whisper in your ear. Let me tell you the thing that I decided while I spent ten years in lockup. Come here and listen to your stupid Da." I felt a guilty pang about ticking him off. He was off his rocker, that much was clear. God knew what he went through in prison. "What, Da?" I said, leaning in close. "Lanie, I'm going to print more printers. Lots more printers. One for everyone. That's worth going to jail for. That's worth anything." (Doctorow 2006: pg.242)

As in this short story, the narratives of the future of 3D printing move between the heroic and the innovative; a technology that can provide ground breaking applications, but that will also fundamentally challenge current structures of societies. This narrative of radical change has been enthusiastically received in a wide range of proactive user communities, many of which have developed their own specific visions of a 3D-printing enabled future (Fordyce, 2015).

I have provided these two vignettes because they represent how graphene and 3D printing embody two different forms of engaging with the future. It is possible to think of these two technologies in relation to what has been introduced as *regimes of economics of techno-scientific promises* (for graphene) and *regimes of collective experimentation* (for 3D printing). The former resembles a linear model of innovation, with strong ideas of competition, urgency and entrepreneurship; the latter relates to ideas of distributed innovation, which is user-centered and aimed at redistributing agency, knowledge and power in technology development and society (Felt & Wynne, 2007). These two regimes or *modes*, as I will call them in this thesis, represent two different ways of engaging with the future

4 The RepRap Project, started in 2005, was aimed at producing an open-design 3D printer that can print most of its part, and hence, self-produce. The project successfully produced one of these printers in 2008, and has continued to grow along with a community of 3D printing enthusiasts.

As I have shown, these modes differ in terms of the future-oriented narratives they involve. In this thesis I explore whether these different narratives of the future are related to different forms of anticipation and, consequently, to different practices. In principle, both technologies are embedded in the same scientific and economic systems, and they embody many of the norms and values of the social contexts in which they develop. Do the practices through which anticipation takes place differ? And if so, why? What are the implications for each technology field?

There is also a normative perspective related to each of these two modes, since they also represent two ways of seeing the world and two models of society. In fact, engaging with the future is in itself inevitably normative. Conceptual terms such as "Anticipatory Governance" and "Responsible Innovation" in fact emphasize that expectations and anticipation are never neutral, but always are instrumental in steering technological developments in socially desirable directions (Barben, Fisher, Selin, & Guston, 2008; Nordmann, 2014) . While I do not address this topic per se, through the empirical study of these practices I explore the underlying frameworks and assumptions that occur in forms of anticipating a technology in society. Ultimately, this allows me to reflect on what it means to have "better" (e.g. more inclusive, resilient, reflexive) forms of dealing with the future.

1.3. Structure of the thesis

This thesis is composed of seven chapters. Chapters 2 and 3 provide the theoretical and methodological background of the thesis. **Chapter 2** introduces and develops a framework to conceptualize anticipation as a practice. To do so, I draw on three sets of literature: the sociology of expectations (Borup et al., 2006; van Lente & Rip, 1998), approaches to anticipation from human geography (B. Anderson, 2010) and studies of performativity of socio-technical assemblages (M Callon, 2007; D. MacKenzie, 2007; Pollock & Williams, 2010). I develop the notion of *anticipatory practices* to study those practices in which the future is shaped, explicitly and implicitly, from forecasts to the development of prototypes. I focus on how these practices, together and in relation to each other, contribute to the constitution and governance of emergent technology fields. In **Chapter 3,** I introduce the methodology I used to study these practices. I call this a "recursive methodology" in which I draw on a series of traditional and digital ethnographic methods to capture multiple practices in different spaces as they evolve in relation to the field. I introduce in detail the two case studies and the criteria and rationales for selecting them.

The three empirical chapters address different aspects of the main research question. They draw on findings from the graphene case, the 3D printing case, or both. The chapters refer to different aspects of the process of anticipation: a) the way anticipatory practices differ across spaces; b) how they are shaped by different logics; and c) how specific specialized "promissory actors" mediate anticipation. **Chapter 4** provides an in-depth case study on the emergence of the graphene field from the perspective of its expectations. It shows, on the one hand, how local anticipatory practices are enabled by existing regimes and, on the other hand, how they transform and produce global innovation dynamics. The chapter shows how anticipatory practices, specific to certain domains such as scientific publishing, science policy or the market, are enacted over time and how they become interlinked. Graphene emerged in the science space and was linked to the promises of Moore's law. The strategic expectation work done by the graphene discoverers, particularly through prestigious academic publications, enabled graphene to be constituted as a research field on its own[5]. The promises of graphene were taken up in a large scale European funding framework, the Graphene Flagship, aimed at developing the economic and social benefits of graphene. Industry actors moreover started to produce a "graphene market," thus strengthening the importance of the economic value of graphene. The chapter shows that some anticipatory practices are specific to certain spaces; these practices in turn produce particular collective expectations (embedded in speech or reports, publications, diagrams, etc.) that can be translated to other spaces, where they are taken up by different actors. It shows that the process of anticipating and shaping an innovation field depends on a gradually emerging assemblage of practices, actors and expectations that move through various spaces, thereby acquiring certain degrees of legitimacy and stability.

Chapter 5 explores the socio-material practices through which anticipation occurs in the field of 3D printing. More specifically, the chapter focuses on the relation between practices, the contexts in which they are embedded, and their respective guiding logics. Anticipation does not only happen in practices that are explicitly targeted at knowing futures, such as roadmaps or foresight exercises, but instead it is part of diverse innovation practices in which innovation actors engage in the production of technology: development of prototypes, organizing innovation communities, fundraising, etc. These practices shape and are shaped by expectations; they are informed by existing promises and concerns and are also strategically aimed at sustaining or changing these expectations. There are two logics that guide the anticipatory practices described in this chapter: techno-scientific and open source. A techno-scientific logic is characterized by big promises and a sense of urgency. An open source logic is characterized by recursive experimentation. What I observe empirically is that in many cases a mixed logic guides these practices. Still, distinguishing these logics is important. The extent to which a specific practice is influenced by one or the other logic will affect the way in which anticipation takes place, thereby shaping the choices that are made in relation to the future of a technology (path dependency) and the degree of reflexivity of these expectations.

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5 Graphene now comprises all 2-dimensional materials, studied from different perspectives (physics, chemistry, engineering, etc.)

Chapter 6 focuses on technology consultants as promissory actors and how the deploy the figure of the "hype-cycle". It shows that these consultants produce a specific type of knowledge about hypes that is based on their experience and interactions with other actors in the field. I argue that knowledge about hypes is co-produced with hypes themselves, and that this knowledge is performative – just as expectations are. In order to know hypes, it is not enough to merely point them out. Hypes also have to be provided with a theory underpinning a particular assessment, and consultants therefore need methods for checking the robustness of the associated expectations. Once knowledge becomes collective, it changes and shapes the respective technology field. This process is mediated by practices that are specific to technological consultants. One of the effects of the work of consultants is the diffusion of specific forms of anticipatory coordination throughout the technology field – i.e., consultants not only offer knowledge about the future, but also actively spread their specific way of anticipating the future to other actors, thus 'colonizing' their anticipatory practices. On the one hand, consultants position themselves against promises and hype dynamics, thereby trying to build up an expert status based on "realistic" expectations and critical assessment. On the other hand, they actively articulate enthusiasm for a certain technology field. By doing so, consultants shape the market for emergent technologies, but also create a niche for themselves as indispensable actors within that market.

Chapter 7 is the final and concluding chapter. Here I provide an overview of my research findings in relation to the overall research question, and I discuss the relation between anticipatory practices and their performativity. I show how this approach allows us to understand anticipation as an ongoing process, and I examine the practical implications of these findings. I make explicit the connections between different chapters and how this contributes to the literature on the Sociology of Expectations, Anticipation and Anticipatory Governance, and to the understanding of the future in social theory in general.

In sum, this thesis, which I have entitled "Mindful Anticipation," draws attention to the practices through which collective expectations are circulated, thereby shaping the very future they refer to. This approach expands existing studies in the Sociology of Expectations by stressing how the way in which expectations are produced in different contexts matters for their performativity. In broader terms, the "mindfulness" of anticipation refers to paying detailed attention to the ways in which the future is produced in the present, as embedded in specific techno-scientific practices, which has consequences for the long-term as well as for the present. My proposition is that it is taking this perspective as a starting point, it is possible to question and modify the ways in which we shape the future of emerging technologies.

2. Framework (*)

(*) A version of this chapter was published as: Carla Alvial Palavicino. "The future as practice. A framework to understand anticipation in science and technology." *Tecnoscienza*, *6*(2) pp. 131–170.

> Zhuangzi and Huizi were strolling along the bridge over the Hao River. Zhuangzi said, "The minnows swim about so freely, following the openings wherever they take them. Such is the happiness of fish."
>
> Huizi said, "You are not a fish, so whence do you know the happiness of fish?"
>
> Zhuangzi said, "You are not I, so whence do you know I don't know the happiness of fish?"
>
> Huizi said, "I am not you, to be sure, so I don't know what it is to be you. But by the same token, since you are certainly not a fish, my point about your inability to know the happiness of fish stands intact."
>
> Zhuangzi said, "Let's go back to the starting point. You said, 'Whence do you know the happiness of fish?' Since your question was premised on your knowing that I know it, I must have known it from here, up above the Hao River."
>
> *Zhuangzi: The Essential Writings with Selections from Traditional Commentaries*

How do I know what I know? In this dissertation I deal with an abstract and slippery concept: *the future*, and in particular, the future as a social practice. It is for this reason that I devote this chapter to making clear the perspective from which *I see* the future as a practice, and which enables me to understand anticipation in emergent technologies. This chapter develops a conceptual framework to understand these processes from a practice-oriented perspective. The chapter is composed of three parts. The first section (2.1) introduces the concept of anticipation as a characteristic form of relating to the future in contemporary life. It argues that the future has become an object of governance, which despite its uncertain nature needs to be known in order to legitimize interventions that take place – in the present – in its name. It shows how, in particular, anticipation is a central category in shaping emerging technologies. The second part (2.2) reviews the central concepts of the Sociology of Expectations, the main conceptual background of this thesis. This includes the notion of "expectations", as well as dynamics such as hypes and their performative effect. This section situates the study of anticipatory practices within the broader field of expectation studies. The third section (2.3) develops the specific analytical concepts and framework that are used in my empirical analysis: anticipatory practices, logics and assemblages. I argue that it is possible to understand anticipation as a set of (anticipatory) practices that compose an assemblage, a specific arrangement of practices which is performative. That is to say, these practices are arranged in relation to each other in specific ways (or specific logics), enabling and constraining specific ways in which expectations are built, shared and contested, and which explain their performative effects.

2.1. Living in the future: emergent technologies and contemporary life

It can be argued that emerging technologies only exist in the future. For many new technologies, what is said, shared, visualized and even traded only exists as speculative statements about their possibilities. Yet, these promises and expectations seem to be forceful enough to create associations, promote investments, market products. In fact, the "compulsion" to look into and act in relation to the future is at the core of capitalist dynamics and liberal democracies (B. Anderson, 2010; Beckert, 2014).

It is for this reason that the future has become a category of social inquiry in itself. A large and heterogeneous set of literature in the social sciences has been devoted to the study of "the future." While traditionally the social sciences have been a past- or present-oriented discipline (Brown & Michael, 2003; Emirbayer & Mische, 1998; Poli, 2014), in recent years scholars from areas such as philosophy, geography, history, anthropology, sociology and STS have engaged actively in the study of the social, cultural and political aspects of the future (Adam & Groves, 2007; Andersson & Rindzeviciute, 2015; Appadurai, 2013; Beckert, 2013).

One theme common to all these approaches is that for contemporary societies the future is highly uncertain. While this might seem self-evident, it is a profoundly contemporary phenomenon to perceive the future as empty, open-ended and unpredictable (Adam & Groves, 2007).[6] Despite this unpredictability, there is an increasing need to act in relation to the future, particularly to prevent potential risks or to profit from big promises. This implies that an uncertain future is made "actionable" by a set of societal arrangements, attitudes and interventions that can be legitimized in the name of what is yet to come (Anderson, 2010; Beckert, 2014; Massumi, 2007).

What can or should be done in relation to the future varies across cultures and historical periods (Koselleck, 2004). Despite their uncertain and indeterminate nature, futures are known through a range of methods. Modern forms of prediction are characterized by a techno-scientific rationale in which calculative and modeling practices play an important

6 In contrast to an unpredictable future, Adam & Groves (2007) refer for example to a "divine future", determined by the Gods, which is a future that can be known, seen and anticipated because it is a pre-given future. This form of future thinking was important for pre-industrial western societies.

role (Schubert, 2015).[7] Adam and Groves (2007) argue that there are three forms of knowledge about the future: (1) the future as an extension of the present, as the consequence of ongoing developments, in terms of its individual, socio-cultural or natural components; (2) the future as a continuation of the past which can be rationally grasped by scientific methods of correlation and calculations; and (3) mapping possible, probable or preferable futures in a non-deterministic way, as a basis for choices, decisions and actions. The last two forms can be observed in modern ways of relating to the future.

Starting from the post-World War II period, a number of specialized methods and institutions have been created with the purpose of knowing and controlling the future. With the establishment of the RAND Corporation and other related institutes across the Western world[8], the future was established as an object of knowledge, expertise and governance (Andersson & Keizer, 2014). These organizations developed methods such as forecasting, Delphi[9] and scenarios to understand future threats or predict success of future technologies. The future emerged "as a field of study, constituted by actors through a wide repertoire of instruments, technologies and narratives, held together by their ambition to shape and reshape the modern world" (Andersson & Rindzeviciute 2015; pg.5).

This range of methods and actors contribute to building-up futures as an element of current societies. The future has become an object of governance, a category of both scientific and political intervention (Andersson & Keizer, 2014). However, it is not a neutral construct; instead, how it is framed, what is included or excluded and who is included or excluded is central to accounting for the choices made, particularly in relation to technology policy decisions (Skjølsvold, 2014). In fact, actions in the present need to be understood not solely as the ultimate outcome of past events but rather as an outcome of ideas and perceptions of the future (Beckert, 2014).

The concept of anticipation captures the modes and effects of acting in the name of the future. It refers to methods of action that are future oriented, in which futures are grasped, known and articulated so that particular interventions can take place (Anderson, 2007, 2010). Anticipation pays attention to the ways in which the future is constructed in the present; it is not about prediction, but about the mutual adjustment between future expectations and current/contingent dynamics.

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7 One recent development is to move from exploratory forms of predictions such as foresight, which are aimed at making visible the forces and assumptions embedded in future thinking to the use of "Big Data". This approach to prediction shows – and creates – trends without paying attention to the forces that explain their existence (Couldry, 2014).

8 The development of techniques and technologies to know and control the future is not just a feature of western democracies. Similar developments can be found in the East, particularly in the ex USSR related to the notion of cybernetics (Andersson & Rindzeviciute, 2015; Barbrook, 2007).

9 Delphi methodology is a forecasting method that is based on the opinions of a panel of experts, based on various rounds in which their opinions are expected to converge to the most likely predictions.

2.1.1. Anticipation in Science and Technology

Anticipation is a process where the present is transformed, intervened in and ultimately governed in the name of the future (Adams et al., 2009; B. Anderson, 2010; Rip, 2012). It is both a cognitive mechanism and a social process (Kinsley, 2012). Schutz (1976) argues that while it is not possible for social actors to predict the future, since it does not have a preexisting ontology, actors still anticipate what is to come and they are interested in controlling it. While anticipation in itself can be considered almost an "anthropological category" proper to all human beings (Beckert, 2013; Poli, 2014), "anticipation" as a form of governance is the result of understanding the future as highly dynamic, uncertain and indeterminate (Massumi, 2007).

Anticipation is an important part of innovation processes, particularly for emerging technologies. It has been argued that promises and expectations play a particularly important role in shaping technological developments (Rip & Van Amerom, 2010; Rip, 2012). Innovation actors coordinate in relation to future expectations through the creation of a shared "agenda" (van Lente & Rip, 1998). Anticipation is enacted by expectations, visions and imaginaries. For example, socio-technical imaginaries shape the structuration of large-technical systems such as energy supply systems, in a process in which an imaginary of a technology as well as an imaginary of society are co-produced (Jasanoff & Kim, 2009; Levidow & Papaioannou, 2013). Also visions and more specific expectations play an important role in shaping technological developments; in fact, in early stages of development, promises about a technology are often overenthusiastic, which promotes collective action but which also leads to exaggeration and disappointment (Dignum, 2013; Gisler, Sornette, & Woodard, 2011; Pedersen & Hendricks, 2013) .

It has been suggested that there are two contrasting forms of relating to the future for new and emerging technologies, in the process of co-construction of technologies and society. These two forms have been characterized as two regimes: techno-scientific or collective experimentations (Felt & Wynne, 2007). These notions aim to capture ideal forms in which future orientation shapes technological development. The *regime of economics of techno-scientific promises (ETP)* is characterized by a linear, top-down and centralized model of innovation. In this regime fictions are used to attract resources, drawing from an uncertain future that stresses competition, but these fictions do not account for the broader societal aspects of a technology. In contrast, the *regime of collective experimentation* (CE) represents a distributed, collective and open process of innovation. In this case the emphasis is on the democratization of technological development and the expectations through the engagement of users and experimentation around new socio-technical configurations (Felt & Wynne, 2007).

These modes represent two normative models of technological developments, which relate to two different models of society that are being performed. In the regime of ETP, promises and hype drive the actions of innovation actors. In contrast, in the regime of CE, the future is not depicted in terms of promises and expectations, but technologies are constructed by free, open experimentation, without attributing to the future a steering role. Such distinction refers to ideal types; it can be expected, however, that empirically, future orientation and expectations both play a role, enacted and mobilized in different ways. Furthermore, for both cases there might be not one but multiple futures, as this is often the result of a nonlinear process in which claims and counterclaims are made and contested (Brown et al. 2000: pg.5).

This normative characteristic of socio-technical innovation has been used to develop approaches to the steering of these processes into desired directions. One of them is known as "anticipatory governance" which can be defined as the capacity to rehearse future possibilities prior to "diving into the future" (Guston, 2014). Similarly, calls for "steering" the development of emerging technologies, recently under the label of "Responsible Innovation", are based on the capacity of actors to anticipate how technologies will become embedded in society (Nordmann, 2014). In particular this last approach has been strongly taken up in policy circles as an (implicitly) future-oriented governance approach to emergent technologies (Simakova & Coenen, 2013).

As I have shown, anticipation as a way of knowing and acting in relation to the future is a central aspect of technological development. Yet it is a complex process that requires a specific arrangement of knowledge, expertise, actors, practices and institutions. In this process, expectations – as promises or concerns – play an important role. It is through expectations that discourses about the future are produced, shaped and circulated. Anticipation and expectations are related, but they are different: anticipation refers to a process in which ideas of the future are made present through knowledge, affects, practices, etc.; this is broader than just expectations, but expectations are central in the process. An extensive area of research has been developed to understand the role of expectations in technological development, known as the *Sociology of Expectations*. In the next section I introduce the main aspects of the study of expectations.

2.2. The Sociology of Expectations

Anticipation today can hardly be separated from techno-science: on the one hand, for every new technology, futures are imagined and mobilized. On the other hand, these technologies are used to portray (and know, and even predict) specific societal futures: they are used as political tools (Beckert, 2013; Brown, 2003; Kinsley, 2011). With new technologies, expectations about the future are circulated in order to obtain resources, and to guide and legitimize innovation processes. Within Science and Technology Studies, an area of research named Sociology of Expectations[10] has extensively discussed the role

10 Brown & Michael (2003) actually introduce this area of research as the Sociology of Futures and Anticipa-

of expectations in innovation processes.

This analytical approach can be characterized "as a detailed examination of forms of action and agency through which the future is both performed (as a temporal representation) and colonized (as a spatial and temporal locus)" (Brown & Michael 2003; pg.5). Its focus is on the examination of the role of promises, visions and concerns, which are largely discursive but also embedded in material practices. In the following, I will introduce and explain the core elements of the Sociology of Expectations that I use in order to characterize and understand processes of anticipation in science and technology.

Expectations, in the form of promises, visions and concerns, play a central role in shaping the socio-technical arrangements of emerging technologies. In cases in which innovation actors are confronted with high uncertainties and indeterminacies (Rip, Joly, Callon, & Arentsen, 2010; van Lente, 1993), these expectations shape the "conditions of possibility" for emerging techno-science (Horst, 2007). Expectations can be defined as "statements about future conditions or developments that imply assumptions about how likely these are supposed to be, and which circulate in a community or public space" (Konrad, Van Lente, Groves, & Selin, forthcoming) . They correspond to collective ideas about the future, in contrast to those belonging to an individual or particular actor group. These collective expectations gradually become taken for granted, as if they were a self-evident statement that does not need to be justified (Konrad, 2006b). Expectations are both discursive (as narratives about desires and future states), and simultaneously embedded in technologies, emerging actor-networks and socio material practices (Konrad 2006a: pg.2). As "wishful enactments" of desirable futures, expectations are highly normative, they embody particular ways of thinking how society should be (Eames, McDowall, Hodson, & Marvin, 2006; Hedgecoe, 2003). These promises or concerns embody specific values, hopes and fears (Milne, 2012), which are always interrelated: as there are big promises, there are also concerns and fears (te Kulve, Konrad, Alvial Palavicino, & Walhout, 2013). Furthermore, their specific content tends to be a reflection of current concerns, promising to solve societal challenges that are relevant for the present. In this sense, collective expectations tell us more about how society is understood today than about the future itself (Konrad, 2006b).

This area of research treats expectations as discursive elements that have an effect in innovation processes. This means that expectations not merely narrate the future, but actually have an effect on the technologies they refer to: they are performative. More than just providing a reference point, expectations contribute to steering the innovation processes (Borup et al., 2006; te Kulve, 2011). They fulfill specific functions and contribute to the configuration of the field they refer to. They mobilize actors and resources, provide guidance and coordination, enable sense-making processes, and legitimize socio-technical arrangements (Brown & Michael, 2003; Swanson & Ramiller, 1997).

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tion (pg. 4).

2.2.1. Performativity of Expectations

The performative aspect of expectations refers to the fact that they are constituent of innovation processes, particularly for emerging technologies. A well-known and extreme case of performativity, which is often considered a self-fulfilling prophecy, is the case of Moore's law (Merton, 1968; van Lente & Rip, 1998). This so-called law refers to the relation between the increase in computing power versus cost reduction. This expectation is largely maintained by the ITRS, an association of semiconductor industries and researchers that yearly forecasts and organizes the future of Moore's law. The success of this prophecy is the result of a highly coordinated network of actors and the strong interdependencies between the semiconductor industries and other sectors (Le Masson, Weil, Hatchuel, & Cogez, 2012; Schubert, Sydow, & Windeler, 2013; Sydow, Windeler, Schubert, & Möllering, 2012).

In contrast to Moore's law, not all expectations present such strong and highly coordinated forms of performativity. Instead, their effect is more diffuse: performativity can only be addressed in hindsight by tracing back the ways in which statements about the future changed and the world they constituted changed in relation to each other. This does not mean a full or complete alignment between expectations and the way technologies develop. In fact, in most cases expectations do not materialize (Bátiz-Lazo, Haigh, & Stearns, 2014; Geels & Smit, 2000); nevertheless, they have a strong effect in structuring and shaping actual developments in a field (van Lente, Spitters, & Peine, 2013). Stressing the performative aspect of expectations is an analytical approach which highlights “the ways in which techniques deployed in marshaling anticipated futures are engaged in reflexive processes of world making” (Kearnes 2013: pg. 459).

Some scholars have suggested explanatory mechanisms for the performativity of expectations. One of these propositions attributes the performativity of expectations to the effect they have in the mutual positioning of actors and the creation of agendas. Van Lente & Rip (1998) have called expectations “prospective structures to be filled by agency”, as they show some of the effects of structures but do not have their endurance and stability. They become forceful through what is called a “promise-requirement cycle” in which a promise is turned into a requirement for innovation actors, which then leads to other promises. These cycles are reinforced by “umbrella promises” (Rip & Voß, 2013), open ended and broad promises that are broadly shared by innovation actors. The relation between umbrella and specific promises happens in a cycle of “dual dynamics of expectations” in which the specific promise-requirements cycles support the validity of an umbrella promise (Parandian, Rip, & te Kulve, 2012). [11]

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11 These umbrella promises are overarching ideas about the future, which in many cases can be considered as visions. Visions are distinct from promises in the sense that they embody general narratives about solving a specific problem that is relevant for society at large, and they come with specific values (Dignum, 2013). For example, a vision is the “hydrogen economy”, which refers to a certain socio-technical system that

Such a perspective draws attention to the relation between expectations as discursive elements, and the effects that the articulation of this discourse has in the activities of innovation actors. However, expectations are not only discursive. They also become embodied in artifacts, institutions and practices. The performative effect of these expectations depends on these material embodiments that mediate their operation, negotiation and circulation, be it in the form of prototypes, standards or procedures (Borup et al., 2006; Hyysalo, 2006; Milne, 2012; Wilkie & Michael, 2009). As explained by Michael (2000) in his introductory work to the Sociology of Expectations,

"The performativity of these representations does not take place in some abstracted, a-material domain. It is conducted in material settings, where bodies and texts, for example, come into contact or close proximity at least." (ibid; pg.292)

More specifically, expectations are embedded in socio-material practices. This is particularly evident in design processes, where expectations of developers, designers and sometimes, users become embodied in prototypes (Hyysalo, 2006). Wilkie (2011) describes prototypes as "expectational devices" with the capacity to "reify the future in the present" –coding of the future as a physical construction embedded in the present. While this performativity approach to expectations has shown that they do have an effect on the constitution of technological fields, and that this means that they fulfill specific functions, it has provided only scattered accounts specifically referring to the forms, practices and materiality that constitute this process. For this reason, I propose to look closely at the broader notion of performativity and re-assess its use in the Sociology of Expectations.

2.2.2. Some general notions of performativity

To weigh the claim of the performativity of expectations it is necessary to dig into the concept itself. While I do not intend to offer a full historical account of the use of this concept, which has also been revitalized in the broader debate about the "ontological turn" (Escobar, 2007; Pellizzoni, 2015; Van der Tuin & Dolphijn, 2012), I would like to discuss its use in one area which is closely related to the study of expectations: the study of economic processes. Callon (1998) has drawn attention to the way in which economics, as an academic discipline, and the economy, as a phenomenon, are reciprocally constituted. The main claim is that "economics is performative". But what does it mean to say that economics is performative? Performativity is described as theories contributing towards enacting the realities that they describe (Law & Urry, 2004). Within this framework, the "social" is understood beyond the dualism agency-structure; agency is action that emerges from within a network in which it is embedded (Michel Callon, 1998).[12] That is to say, the social

provides clean and sustainable energy. In relation to these broad visions, the more specific expectations might refer to the role technologies, institutions or certain actors groups play in fulfilling this vision.

12 He gives the example of the notion of social capital, which introduces this dualism by thinking in terms

is not an external category, a specific type of "substance", but it accounts for the formation of linkages – the assembling - within a network of heterogeneous elements, and it is present only as long as it is performed (Latour, 2005). In this context, agency is performed in certain *socio-technical agencements*, roughly translated from French as "arrangements" or "assemblages" and which I will call assemblages. Agencement, with its root in the word "agency" is not just a network; instead, it stresses the capacity of these assemblages to act or operate differently in different configurations. In other words, the way these heterogeneous elements are arranged explains its capacity to act in the world and its effects (MacGregor Wise, 2014). An assemblage includes elements as diverse as meanings, discourse, material elements, actors, institutions, networks and practices, and involves the process of arranging, organizing and fitting these elements – it is a "becoming" that brings things together (ibid).

These agencements explain the relation between statements and their worlds; agencements have the capacity of acting differently depending on their configurations or positions in the actor-network. The effectiveness of statements cannot be dissociated from the position they come to occupy in certain socio-technical agencements (Michel Callon, 2009). This approximation reframes the conception that ideas can be true or not true by emphasizing how the world that an idea or a theory describes is actualized in the process. It considers the social not as given but instead as performative, which means that the definition is valid as long as it is performed, and for the same reason, it might disappear or change (Latour 2005). The actualization depends on the constant adjustment of the theory, but also of the world to this theory (Michel Callon, 2009).

One can think for example that ideas such as patterns of technological change are persistent because actors think they are persistent. From this perspective they resemble self-fulfilling prophecies: a firm would believe that other firms will take a certain trajectory, and for this reason they will follow the same path (D. A. MacKenzie, 1998). However, not all performativity is like a self-fulfilling prophecy. MacKenzie (2007) proposes four types of performativity. *General* performativity refers to the cases in which an aspect of economics, such as a theory, model or concept is used by participants in the economic process. *Effective* performativity occurs when the practical use of an aspect of economics has an effect on economic processes (irrespective of what the exact effect is). *Barnesian*[13] performativity is the most extreme case, and it occurs when the practical use of an aspect of economics makes economic processes become more like their depiction by economics. Last, *counter performativity*, which also refers to self-negating prophecies, corresponds to the cases in

of action and resources. Instead, however, he argues that the "social capital" of an actor is given by its relations within a network and the ability to mobilize them (Michel Callon, 1998).

13 Barnesian performativity is in reference to Barnes' notion of performativity "I have conceived of a society as a distribution of self-referring knowledge substantially confirmed by the practice it sustains" (Barnes, 1988)

which a practical use of an aspect of economics makes economic processes less like the description.[14]

These definitions of performativity are useful when assessing processes that took place in the past, but they do not refer explicitly to emergent processes, i.e. to the constitution of what is not yet there, and might never be there – such as the future (Massumi, 2007). The question arises of how the performativity of expectations should be assessed in such cases. As mentioned earlier, the performative effect of expectations can only be assessed in retrospective. This is particularly troublesome for the study of emerging technologies in which no stabilization has yet been achieved.

There is a second aspect to this notion that gives more clues regarding possible empirical research strategies. The notion of performativity brings attention to the materialities that comprise a certain agencement, which explains the occurrence of unexpected and independent events that are beyond what is formulated in theories or models, and yet are the performative effect of these agencements. Performativity is not about creating but about making happen (Callon 2007). The effectiveness of a theory – or a statement, or an expectation – lies in what it does; and this does not happen by acting alone, but it operates through its embedding in a system of institutions, sets of information, agencies, resources, etc. (Mitchell, 2007). Performativity points to the fact that for statements to be true it is not just a matter of implementing an idea in reality, but rather, it is a question of assembling and aligning diverse components and practices so that they might operate as a more or less stable and coherent working ensemble, even if the stability was always only transient. Central to that process of forming a working ensemble, are the instruments that link or mediate between the various elements (P. Miller & O'Leary, 2007). As such, performativity is a social process, not an effect. As explained by Didier (2007)

> "Rome cannot be changed in a day. That is why the process is diluted over time, and the theory is said to act only *gradually.* So the world does not arise, like Athena, fully armed and shouting cries of victory; rather, it came, *little by little*, to conform to economic theories". (pg. 300, emphasis in the original)

This means that in order to trace performativity we need to pay attention to the small adjustments that happen in the world in which a statement or an idea aligns to resemble

14 The 'ends' of Moore's law, that is, the expectation that at some point it will not be possible to continue with the pace of innovation dictated by this proposition has been present since the 1960's. This can be understood as a self-negating prophecy. But this end has not been reached and moves every year further and further away in the future making "the ends of Moore's law" a self-negating prophecy. The performance of these self-fulfilling and self-negating processes is achieved by active orientation and coordination of interested actors to the future; in this case through the ITRS (reference). Both the negating and fulfilling side of the prophecy reinforce each other, creating the conditions for coordination to emerge. Most importantly, the emergent phenomenon, Moore's law, is more than what any actor on its own could achieve or expect, there is de-facto governance happening.

the reality it describes. Particularly, to the material practices and institutional conditions that enable this performativity to take place, and that change through the process as well. This understanding draws attention to the way in which the material and the discursive world constitute each other.

The materiality in which the future, and the anticipation of this future is embodied is fairly evident. In recent years methods and actors have emerged that are specialized in the production of expectations and the coordination of anticipatory processes. Among these, there are consultancies (Pollock & Williams, 2010), specialized media providers (Morrison & Cornips, 2012) or think thanks (Wilkie & Michael, 2009). Particularly interesting is the emergence of specialized expectations actors, organizations whose role is to act as intermediaries in the production, circulation and performance of expectations. Pollock & Williams (2010) have introduced the term "promissory organizations" to refer to these consultancies, whose role is to produce expectations – or knowledge about the future, to be used by other innovation actors in emergent technologies. This type of future knowledge is of a very particular nature, since it is associated to a type of expertise that is highly interactional and requires the embodiment of the object studied (Evans, 2007; Pollock & Williams, 2015; Reichmann, 2013). [15]

Such developments stress how the institutionalization of the future has become a matter of inquiry, intervention and, consequently, of governance. As I have suggested earlier, this trend has been developing since the 1960s and has become stronger in relation to notions of risk (Beck, 1992). This is particularly striking for new technologies. Their development is often a process of weighting and negotiation between promises and concerns, which means that expectations are a core element of governance processes in emergent technologies (Rip, 2012). I suggest that governance aspects can be grasped by thinking in relation to the performativity of expectations.

2.2.3. (de facto) governance of and by expectations

Governance can be understood as an analytical perspective that makes comprehensible complicated processes of collective action at the level of the state, the economy and society (Benz, Kuhlmann, & Sadowski, 2007). It corresponds to forms of coordination among heterogeneous but interlinked actors, which involves political guidance as well as forms of self-control and self-regulation (Mayntz, 2003). Such forms of coordination can be characterized as hierarchies, networks, markets or negotiations (Benz et al., 2007; Treib, Bähr, & Falkner, 2007).

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15 Producing knowledge about economic futures is a process in which the experts "embody", actively represent parts of the object of study that is shaped by the interaction with other experts. In this way, economic and technology forecasters can acquire knowledge about the future of the object of study by the interaction with other relevant experts (Reichmann, 2013).

Taking a governance perspective to the study of expectations and anticipation means to focus on the way expectations and associated anticipatory practices contribute to collective action in a technology field. This perspective has been developed under the notion of *anticipatory governance*, either as an analytical concept (Anderson, 2010) or as a normative framework (Barben et al., 2008). Both refer, from different angles, to the role of "the future" in coordinating action in the present. A more specific perspective is introduced by the notion of *governance of and by expectations,* which has been introduced to capture the different modes in which expectations contribute to the coordination of innovation processes. *Governance of expectations* refers to the way in which expectations themselves are coordinated by the activities of innovation actors; *governance by* expectations refers to the fact that expectations influence innovation (Konrad & Alvial Palavicino, 2015). It is important to note that this is an analytical distinction, and that in reality governance of and governance by are part of the same processes.

Rip (2006, 2012) has argued that anticipation is proper to any governance process, and that it has in particular a relevant role in shaping emergent technological fields. Expectations about particular futures can solidify into a societal agenda to govern strategic choices – what he calls "delegation to the future". From this angle, expectations contribute to *de facto* governance of innovation through this structuring effect, by enabling and constraining, coordinating and orienting innovation activities, which is often an unintended and collective effect of their circulation (Konrad, 2006a). In this way they contribute to lock-in and path-dependency, by promoting some alternatives and excluding others (Konrad, 2006b). De facto governance refers to the patterns and structures of coordination that emerge largely non-intentionally from the interaction of many actors, through mutual dependencies of perspectives and action (Rip & Van Amerom, 2010; Rip, Voss, Bauknecht, & Kemp, 2006). *De facto* governance can be understood as a patchwork of governance arrangements. Nevertheless, they are interrelated; in fact, intentional governance can be considered one element of de facto governance.

A way of thinking about governance of and by expectations is in terms of their performativity. Performativity is about reconfiguring reality, which has to be transformed in order to fit the models and expectations that represent it (Voß, 2014). In this respect expectations relate to processes of collective action by which innovation actors intentionally or implicitly align their activities to future expectations. These processes enable, for example, the structuration of emergent fields (Kearnes, 2013). In addition to a performativity perspective, a governance perspective stresses the relation between local developments and global effects, seen as coordination at the level of society or the economy. This can either be the aggregated effect of multiple local practices, as well as the effect of specific practices that have the particularity of connecting the local with the global effects. For example, publishing a research paper in a high-impact journal can potentially increase immensely the visibility of a research area and its promises, and serve as a starting point for its expansion.

It is important to note that performativity, as governance, is a two-way process, in which both expectations and the world they represent align to each other through the activities of innovation actors. As I have pointed out in discussing the performative effect of expectations in innovation, expectations also have dynamics of their own which are influenced by changes in the innovation field. In fact, there are explicit attempts to "govern" expectations, as reflected by the development of future-oriented methodologies, and the emergence of specialized expectations actors (Pollock & Williams, 2010). These developments reflect the active and reflexive action of innovation actors, who are aware of expectations, their dynamics and role in innovation, and strategically and actively influence expectations for their objectives (Konrad, Markard, Ruef, & Truffer, 2012).

The dynamics of expectations show temporal and spatial variations, as well as a variation in the effects they have in different actor groups (Borup et al., 2006; Brown & Michael, 2003). The variation in the type (from positive to negative) and attention of expectations is known as the "hype-cycle". This cycle, introduced in the ICT world by the Gartner group consultancy, describes cycles of media attention and content of expectations that go from overpromising through disappointment to stabilization (Fenn & Raskino, 2008). Besides its particular use by the Gartner group as a tool for management of emerging technologies, hype-cycles have been identified as a recurrent pattern in expectations dynamics often referred to in expectation studies. I will thus detail the main aspects of this cycle in the next section.

2.2.4. The dynamics of expectations: Hypes

For many emerging technologies it is often the case that early expectations are overoptimistic. This optimism might lead to exaggeration, followed by disappointment when these promises are not fulfilled. From high temperature superconductivity (Felt & Nowotny, 1992) to fuel cells (Bakker & Budde, 2012; Konrad et al., 2012), and the hydrogen economy (Dignum, 2013), and from genomics (Fortun, 2008) to biotechnology (Gisler et al., 2011) multiple technologies and technological concepts have gone through one or many cycles of high attention followed by disappointment – also known as "hype cycles". While hypes might have a negative connotation, they are at the core of innovation processes in emergent technologies (Brown & Michael, 2003). Hypes are often referred to as the result of "unwarranted and exaggerated claims which make an emotional appeal to the audience" (Guice, 1999) which are used as a particular rhetorical strategy in order to mobilize resources (Ramiller, 2006).

In general, hypes and hype-cycles are understood as the circulation of over-exaggerated promises, often through media, which might lead to unfounded excitement and disappointment. But before going into extensive discussions about the dynamics of hypes, it is first necessary to introduce some clarifications about the use and definition of two common understandings of the notions of *hype* and *hype-cycle*. Hype is commonly understood as the act of exaggeration of the promises and expectations of a technology. Often accusations of hype emerge in scientific discourses, being attributed to the system of incentives and competition of science. Hypes are closely entangled with the system of press releases and media relations (Caulfield & Condit, 2012; Master & Resnik, 2013; Nerlich, 2013; Rinaldi, 2012). Similarly, hype as an act of exaggeration is a common feature of the discourse of technology actors – it often fulfills a strategic function for the diffusion and long term development of the technology (Gisler et al., 2011; Ramiller, 2006).

On the other hand, the hype-cycle is used as a methodological tool developed by the consultancy organization "the Gartner group" in order to assess the credibility and maturity of new technologies. This tool has been strongly established in the imagination of innovation actors, becoming a shared belief or "folk-theory" among innovation actors (Rip, 2006) who might look for signals of hype and anticipate its occurrence. It describes a cycle of media attention and expectations composed of five stages (1): technology trigger, peak of inflated expectations, trough of disillusionment, slope of enlightenment and plateau of productivity (Fenn & Raskino, 2008).

Thus, there may be two understandings of hype: one that refers to the active production of exaggerated claims (that is, to hype) and one that focuses on the collective effect these exaggerated claims have in the field, and on what this tells us about the technology (hype-cycles). I would argue that to understand hypes it is necessary to use a hybrid definition situated between two distinct ontological levels: the action of hyping and the meta-level phenomenon of hype. In this definition, hype-cycles are more than the sum of individual actions and more than the additive effect of exaggerated claims: hypes have intentional and unintended effects to which innovation actors need to respond (Konrad et al., 2012).

It is this last understanding of hypes that I want to develop further. By doing so, I propose to understand the performativity of expectations in the context of hypes as the active assembling, or bringing together, of multiple elements which constitute emergent technology fields. Such assembling can take different forms, which often do not fit the description of the Gartner group. Their shape and extension varies considerably: there are technologies that can go through several hype cycles, and the depth of the disappointment and the extension of the peak will vary across different technologies (van Lente et al., 2013). For example, the case of high temperature superconductivity during the 80s is one of very sharp and short hypes (Felt & Nowotny, 1992). In contrast, fuel cells (Ruef & Markard, 2010) or artificial intelligence (Gomes, 2014) are technologies that have been through multiple cycles of hype and disappointment without losing out all their credibility.[16]

16 The case of artificial intelligence is particularly interesting, because although the vision itself is rather

Innovation actors are aware of these cycles of expectations and might strategically respond to them by getting involved in raising high expectations (Ramiller, 2006) or develop specific innovation activities in moments of strong attention, such as investments, launching products or press releases, etc. (Konrad et al., 2012). While core innovators or developers of a technology make long term commitments to certain expectations, even during disappointment, other actors might enter or exit the field during different stages of the hype (Dignum, 2013). Even those who do not agree with the promises would react and develop strategies in relation to hypes (Gisler & Sornette, 2013; Konrad, 2006b). Particularly interesting is the case of venture capital markets that behave like and are closely coupled to hypes (Gisler et al., 2011). Investors would react in relation to the expectations about the technology but also in relation to expectations about the behavior of other financial actors; thus, they need to understand the hype to develop their own strategies (Wüstenhagen, Wuebker, Bürer, & Goddard, 2009). Thus hypes do not only rearrange expectations but also affect the relations between innovation actors. For example in the way venture capitalists change their attitudes towards opportunistic investors who seem to be responding to hype, in which case they anticipate disappointment and exit strategies.

These accounts show that hypes are constructed not only by the uttering of a certain type of discourse, but also by the actions of actors, enabled and embedded in specific material settings. In this respect, the analogy between hypes and "social bubbles" highlights that such hypes emerge and produce strong social interactions- they reinforce feedback cycles that lead to extraordinary commitments for a technological project, and they create entanglements of financial resources, technical capabilities, hopes and expectations and investments (Gisler & Sornette, 2010). This understanding of hypes stresses two important aspects: the first is that hypes are the result of a process of assembling heterogeneous elements, and that hypes can therefore be understood as an assemblage. Secondly, because this particular arrangement fulfills certain social functions, a hype itself can be considered to be performative. Therefore, it is possible to think of the performativity of hypes as well as the performativity of expectations. As I will show in the next section, this implies that we can interpret hype dynamics and its effects by conceptualizing it as a set of practices embedded in an anticipatory assemblage.

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old (one could say at least more than 100 years) and it has gone through several disappointments – the last in the 80s – it is going through a recent revival under the notions of "big data" and "machine learning." One example of this current hype is the Human Brain Project, which has been funded as an European Flagship project, and which has a strong emphasis in the development of brain-like computing mechanisms (Frégnac & Laurent, 2014).

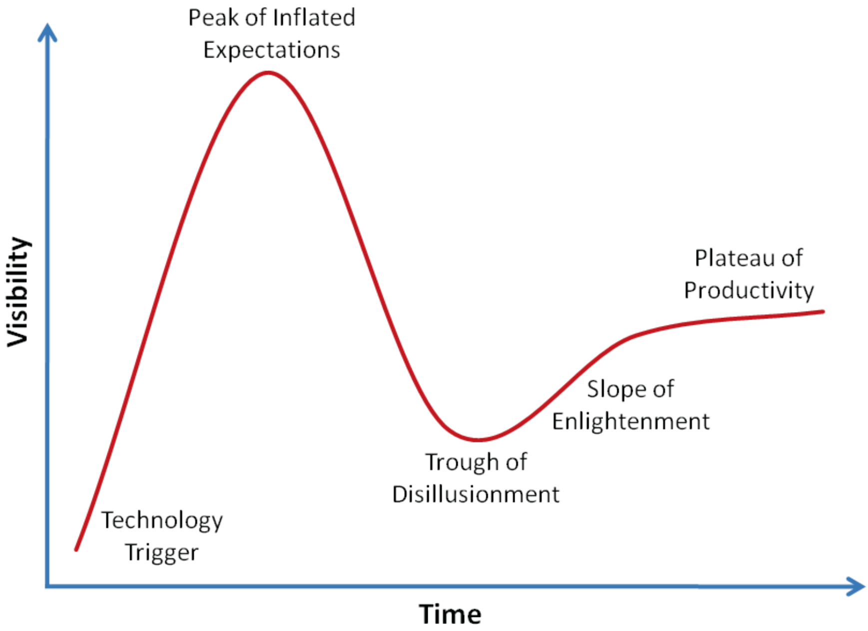

Figure 1: Gartner's hype cycle. Source: Wikimedia Commons, under Creative Commons license.

2.3. Anticipatory Assemblages: Understanding anticipation through practices

In this section I further develop the key analytical terms with which I conduct my study. I have introduced earlier the notions of performativity of expectations and hype as anticipatory assemblage. To understand these two aspects and their interrelation, I focus on practices, as they are related to anticipation. This perspective stresses the material embedding of expectations (Brown & Michael, 2003), and the way in which the active arrangement of expectations leads to overall patterns and patchworks of performative expectations. Through this approach I want to make explicit how the local performativity of expectations leads to changes at the level of a technology field – or even global changes. In other words, I am interested in the question of how specific ways of doing expectation work in specific local contexts contribute to the construction, stabilization and governance of an emergent technological field.[17]

Motivated by this question, I focus on the study of practices in processes of anticipation in emergent technologies. I will call the socio-material practices in which expectations are embedded *anticipatory practices*, following and further developing the approach introduced by Anderson (2007; 2010). By doing so I want to understand how expectations are produced, and what the conditions may be that enable their production and performative character.

The study of anticipatory practices is not completely new to STS. Studies have focused on either implicit and situated design practices (Hyysalo, 2006; Kinsley, 2012; Wilkie, 2011) or the study of explicit forms of expectation work, such as foresight. These latter are explicit techniques and tools used for knowing and anticipating futures (van Lente, 2012). However, these accounts are limited to the analysis of local and specific practices, and say little about the relations that emerge between different practices. Against this background, I am interested in how local and specific practices produce macro scale phenomena, such as hype-cycles. To explore this aspect I use the two empirical cases that I have introduced earlier: graphene and 3D printing. These two technologies have recently gone through a phase of hype, as indicated by the strong attention and over-optimistic expectations that surround them.[18] Nevertheless, there are important differences: graphene stands for a science-push discovery that is turned into a commodity. In contrast, 3D printing is the result of the activities of user communities; it represents a bottom-up development

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17 It is important to note that by introducing local/global relations I do not refer to distinctions such as micro/meso/macro that have been introduced earlier in the study of expectations (Konrad et al., 2012; van Lente, 1993). This is to say, I do not consider different levels of expectations, but instead I consider the processes of assembling expectations, actors, practices which lead to the temporal stabilization of a specific field.

18 An assessment of the hype for both of these technologies is presented in Chapter 3.

that is now being taken up by market actors. These two technologies, while both hyped, embody (in principle) different forms of doing "techno-science" (Nordmann, 2010), which can be roughly related to the *regime of economics of techno-scientific promises* and the *regime of collective experimentation* (Felt & Wynne, 2007; Joly, 2010) that were introduced earlier in this chapter. While graphene follows the path of a scientific discovery that is transformed into a marketable technology, 3D printing is a "grassroots"[19] technology that is in the process of becoming a mainstream technology. The type of actors, institutions, networks and even expectations of these two cases are different, however, strong similarities can also be identified.

In what follows, I introduce the analytical categories that allow me to explore the relations between local anticipatory practices and global dynamics for emerging technologies. Since the notion of practice as a core element that configures social life is central to my approach, I will start by revisiting the very notion of practice, and later build up conceptually, in order to address the complexity of the emergence of technological fields.

2.3.1. Practice theories

Practices are one common form to conceptualize "action", and a way to understand agency (ref). Science and technology studies have made use of this perspective to study science not only as knowledge, but as "practice" (Latour, 1987). This approach stresses the material culture of science, which is neither knowledge nor social relations; rather, science is understood as a hybrid between the material and the social (Pickering, 2008). Similarly, practice approaches have been used to understand the development of infrastructure (Bowker & Star, 2000), organizations (Orlikowski, 2007), marketing (Araujo, Kjellberg, & Spencer, 2008), etc. Along these lines, Anderson (2007; 2010) has introduced the notion of anticipatory practices, to refer to those practices that actively contribute to shaping "futures."

As stressed earlier in this chapter, the importance of the future for the governance of current societies is reflected in a range of institutions, actors and methods that are devoted to understanding and shaping future knowledge and expectations. The example of methodologies for technology forecasting, such as foresight, is revealing. These methodologies have evolved from probabilistic forms of anticipation into more open and exploratory approaches that study alternative futures and their underlying frameworks (Martin, 2010). This example shows that the active engagement with the future, and the development of anticipatory practices, has a history and trajectory of its own. As Anderson

19 Some of the aspects of consumer 3D printers, such as their inception in hacker and makerspaces, and development of initiatives such as FabLabs can be considered "grassroots". By this, I refer to a bottom-up development which lacks a hierarchical governance structure and that resembles a social movement to some extent. For a critical review on the topic see Smith et al. (2013)

(2010) argues, these practices are central to understanding future-oriented governance in liberal democracies; they guide and legitimize action in the name of the future. I will go one step further and argue that this future orientation is not only reflected in explicit practices aimed at shaping the future (as methodologies, methods, tools, etc.) but also embedded in other common techno-scientific practices, from grant applications to venture investment. Techno-scientific practices are a common research object in Science and Technology Studies, but in addition to existing studies, I am interested in how these practices contribute to expectation dynamics. For example, what is the role of a practice such as filing a patent for a new technology in promoting and/or shaping certain expectations? How does it relate to other practices and, particularly, to more explicit forms of anticipation?

Despite his interesting analytical perspective, Anderson does not provide a "theory of (anticipatory) practices" in detail that could guide an in depth analysis. Thus, I'd like to clarify what a practice means in the context of this dissertation and how it informs my approach. Practices are essentially forms of collective action (Barnes, 2001) that generate order in the social world as a relational and performative effect (Law & Lien, 2013). They are a form of routinized behavior, but the routines in question can be filled in multiple ways (Glynos & Howarth, 2007; Reckwitz, 2002), involving both humans as well as technical artifacts (Pickering, 2002). In fact, practices can be understood as a set of elements, which includes materials, meanings, competences, etc. that are brought together by the act of "doing" (Reckwitz, 2002).

In introducing a conceptual definition of practice it is important to keep in mind what I want to learn about emergent fields from the study of anticipatory practices. As implied by my research question, I am interested in the role of expectations in the emergence, shaping and structuration of technology fields. This means, I am interested not in the detailed accounts of a practice but rather in how practices evolve in relation to a field and its expectations. In order to do so, I follow the practice approach introduced by Elizabeth Shove et al. (2012). This approach differs from ethnomethodological approaches that produce detailed accounts of relatively stable social practices (Orlikowski, 2007; Suchman, Blomberg, Orr, & Trigg, 1999). Instead, Shove's approach focuses on the way practices evolve and change. For example, Shove et al. (2012) describe how the practice of driving a car has evolved from the end of the XIX century to the present. This includes not only changes in terms of technologies, but also in the competences required to ride a car (more evident now with self-driving cars) and the meaning attributed to the practice. In this context, my intention is to understand the role of specific anticipatory practices in technology fields, and how they relate to other practices and to changes in the field itself. As Shove states, paraphrasing Latour, the approach allows to follow the practices and in this way understand the social.

Shove et al.'s (2012) notion is composed of a double conceptualization of practices, both as *entities* and as *performances*. This double definition highlights the interdependencies between multiple elements. A practice exists as,

> "a recognizable conjunction of *elements*, consequently figuring as an *entity* which can be spoken about and more importantly drawn upon as a set of resources. At the same time practices exist as *performances*. It is through performance, through the immediacy of doing, that the 'pattern' provided by the practice-as-an-entity is filled and reproduced" (ibid: pg. 7, emphasis in the original).

This definition refers to two aspects of practices: first, practices are *performances* that take place in a certain spatio-temporal context, and they are unique every time this happens. It is important to note that "performance" here is different from the Callonian notion of performativity that I have introduced earlier. Performance of a practice means "doing" a practice, the act of making a practice happen or when a practice takes place. Second, practices as *entities* are referred to and talked about, i.e. there is a recognizable meaning of a practice that is more or less unchanged between performances (Feldman & Pentland, 2003; Shove et al., 2012). This aspect highlights that practices, despite their repeatability, are inherently improvisational, and that the way they are carried out is always somehow novel. It also draws attention to the material aspect of these practices that is mobilized when they are performed, and it underlines that practices have a meaning beyond individual instances of enactment.

2.3.2. Anticipatory Practices

To conceptualize anticipation as a set of practices, it is necessary to introduce some specifications about the type of practices involved. Anderson (2007, 2010) introduces the notion of "anticipatory practice" to speak of and analyze the practices involved in processes of anticipation.[20] Anticipatory practices are practices that give content to futures, and make them present through specific materialities (Anderson, 2010). These practices range from calculation techniques, forms of imagining futures such as scenarios, to forms of performing futures such as gaming, role-playing, etc. In that sense, anticipatory practices

[20] Anderson (2007, 2010) introduces the broader concept of "anticipatory action," a framework to understand future oriented interventions. This is defined as the "seemingly paradoxical process whereby a future becomes cause and justification for some form of action in the here and now " (pg. 778). He is interested in the relation between the future and particular modes of future-oriented governance in liberal democracies such as preemption, prevention, and precaution. More broadly, he is concerned with the particular mechanisms that enable these processes to happen in the first place. He argues that futures are anticipated in the assembling of three elements: styles, practices and logics. While I do not follow his approach fully, I take the notions of anticipatory practice and logics and develop an interpretation that is adjusted to my research interest.

are collective and involve the circulation of collective expectations (Konrad 2006). The notion of anticipatory practices accounts not only for those practices that are explicitly performed in order to give shape to specific futures (as is the case for forecasts, models, trends and so on), but also practices which implicitly shape future expectations and contribute to the process of anticipation, such as setting up standards, prototyping, filing patent applications, etc.

Drawing on Anderson's work as well as the conceptualization of practice by Shove et al (2012), I propose to develop the notion of "anticipatory practice" further. In general, practices can be considered anticipatory if some form of future orientation is at the core of the practice itself. Everything that people do has a history and a setting and is in principle future oriented (Schatzki, 2010). Nevertheless, not all practices are anticipatory. I introduce here a more strict definition of anticipatory practices, in which a practice can be considered anticipatory if it fulfills two conditions: firstly, that the meaning attributed to it relates to a non-immediate and collective future. This means that anticipatory practices refer to futures that are remote enough to be uncertain, and on which a variety of actors have to agree and ultimately act, despite their uncertain nature; e.g., practices which are expected to have a long-term effect such as investments (Wüstenhagen et al., 2009). Secondly, a practice is anticipatory when expectations about the future are mobilized in doing the practice, and as a result, other future oriented activities are triggered; e.g., a practice that enables the circulation of expectations such as the writing of policy reports on technology policies (Wilkie & Michael, 2009).

I will illustrate this definition with two techno-scientific practices relevant to graphene and 3D printing. The first case is the graphene roadmap developed in the context of the application process to the Flagship funding scheme. This collective practice is presented as a way to understand what is the most plausible future of graphene, both in terms of science and applications. In this way, graphene's full potential to create social and economic growth can be developed. Creating such a roadmap requires compiling and coordinating the expectations of a large and diverse community, from researchers to industry to investors, and it is composed of many micro practices such as gathering opinions through a website, expert meetings, etc. The effect of such a practice is to enable this future coordination by creating a certain structure, or promoting certain roles to specific actors within the field. It also serves as a legitimizing device for innovation activities, as I will show in Chapter 4.

A second example is the creation of standards. The creation of technological standards is always a process caught between being too early to have concrete definitions, or too late to regulate (as in the line of Collingridge's dilemma (1980)). Standards are necessary for the diffusion of a technology, so while there is no certainty that a particular product will succeed in the market, its diffusion can only take place when there are appropriate standards to support it. For this reason, actors involved in standardization processes have to anticipate the possible socio-technical configurations of the technology in order to develop useful standards. This process is not devoid of contestation, as many of the actors involved in the process have their own ideas and agendas about the best configuration possible, for which they mobilize and attempt to position certain expectations. Thus the meaning of the practice is related to the future embedding of a technology in society. To perform it, actors strategically mobilize expectations to push for their particular interest in the process. The outcome of the practice has a strong impact on path dependency: it will enable certain developments while excluding others.

With these two examples I wish to highlight that for a practice to be considered anticipatory, it is not necessary that they aim explicitly at shaping expectations. However, it is necessary that "the future" contributes to the meaning of the practice, that expectations take part in the practice itself, and that its performance contributes to anticipation. While this definition helps me to identify those practices that are anticipatory, it does not explain why some practices are preferred over others in a given context. To characterize the conditions that structure (e.g. enable and constrain) anticipatory practices or sets thereof, I use the notion of *anticipatory logic*.

2.3.3. Anticipatory Logics

As I will argue in the empirical chapters, the hype in graphene is based on a different set of practices than the hype in 3D printing. While it seems intuitive that different actor groups, such as scientists versus venture capitalists or industries, would engage in different forms of anticipation, it is nevertheless important to analyze what the conditions are that enable different practices to take place in each case. These practices produce and sustain a specific social order; however, this order is not static. In fact, when different actor groups come together, as in the case of the production of the consumer 3D printer (where hackers, makers and industrialists meet), practices change and new ones emerge. In this respect, a concept such as "logic" captures the relation between a diverse set of practices and their context, and how this set of practices evolves.

"Logic" refers to the "grammar" or rules of a set of practices, and the conditions that make the practice both "possible and vulnerable", or the conditions of possibility or impossibility of a practice (Glynos & Howarth, 2007).[21] "Anticipatory logics" refer to "a coherent way in which intervention in the here and now on the basis of the future is legitimized, guided and enacted" (Anderson 2010, pg.788).[22] We can think of this concept in terms of two forms

21 Glynos and Howard (2007) introduce three types of logics: social logics are related to the maintenance of certain practices, political logics are related to challenge and transformation, which leads to transformations in institutions, and fantasmatic logics account for why a specific practice and regime grip subjects, or the resistance to change of social practices.

22 In particular Anderson refers to logics that are mobilized under potential threats, and that involve actions

of acting in relation to future threats: precaution and preemption. The logic of *precaution*[23] operates under the assumption that through a precautionary act a catastrophic event will not take place, i.e. stopping something before it reaches the point of irreversibility (ref). In contrast, a *preemptive* logic puts emphasis on action under complete uncertainty about a future event, but in a world of strong interdependencies (ref). It does not follow the logic of risk as a calculable entity, and instead acts in the face of indeterminacy of the nature of a threat.[24] There is a fundamental difference between precaution and preemption: the former acts upon processes that are known, on empirically apprehended threats. The latter calls for action on threats that have not yet emerged or even been fully identified. These two logics embody two different ways of knowing the future – and the assumption of what can be known and by which means – which enable different forms of intervention, and ultimately, different forms of anticipatory governance.[25]

These forms of acting upon the future can be related to or can originate from idealist or ideological discourses (Kinsley, 2011 anticipation). As I will show in Chapter 5, different logics can co-exist in a certain field such as the case of 3D printing. For this technology, at least two different logics characterize anticipation: *techno-economic* and *open source*.[26] While the former characterizes practices in which the future is associated with a sense of urgency and competition; the latter refers to practices in which the future is reflexive and a space for experimentation. A techno-economic logic will include practices such as the economic assessment of promises and risks, or the spread of high expectations through media. An open source logic, in contrast, emphasizes practices such as the development of open source hardware and open standards, in which the specificities, aims and ethos of the machine are negotiated among members of a community.

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that aim to prevent, mitigate, adapt to, prepare for or preempt specific futures"(Anderson 2010, pg.779). Nevertheless, these logics need to be constantly reassembled for each of the cases in which they are enacted, which explains their transformative capacity. These logics function as a repeatable means of instantiating the conditions for anticipation – which are based historically on the presumption that certain forms of knowing the future are possible (Kinsley, 2012). In fact, forms of prediction and anticipation are often a highly contested, yet contingent and culturally inflected activity (Andersson & Keizer, 2014).

23 A well-known example of the logic of precaution is the "precautionary principle" which states, "when an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" (1998 Wingspread Statement, from http://www.sehn.org/ppfaqs.html)

24 Massumi (2007) uses as an example of the logic of preemption the American invasion to Irak in (2003), an event that was justified on the basis of a threat that was not concrete, nor could be identified by any method.

25 I use the term "anticipatory governance" in the way Anderson (2010) does. Thus, it is important to distinguish it from the more normative understanding of "anticipatory governance" (Barben et al., 2008) which has been developed in the context of steering innovation processes.

26 These two logics are related to the two regimes as introduced by Felt & Wynne (2007) and Joly (2010): economics of techno-scientific promises (techno-economic) and collective experimentation (open source).

A logic provides a certain way of seeing and knowing the future, codifying for specific practices and setting a specific context for a present sense of futurity (Kinsley 2011). In this sense, logics "enable and constrain" certain ways of knowing and acting in relation to the future, and for the same reason they can be subject to dissent and contestation (Brown et al. 2000). Thus, there is a political dimension to anticipation. While I will not explicitly study this aspect in detail, it must not be ignored, especially when framing expectations in relation to governance. Beckert (2014) has emphasized the distributive and political dimension of expectations and anticipation. He argues that,

> the contingent nature of expectations makes them open to interest-based politics. If decisions have distributive consequences, and if decisions are based on expectations, then actors have an interest in the expectations of other actors. Influencing expectations has become a central task of both political regulation and business and is a major part of discourses on business and the economy (ibid: pg. 11).

The "politics of expectations" are played out, for example, in the way open source 3D printers are developed and promoted against proprietary technology. Similarly, it is embedded in the way the "future of graphene" becomes a European project by rearranging a scientific, technological and industrial community in the flagship initiative, with the purpose of exploiting the economic promises of the material. In order to account for this political aspect, I will pay attention to the normative considerations and ideological commitments that inform certain practices, as well as the way in which anticipation creates inclusions and exclusions.

2.3.4. Anticipatory Assemblages

In order to fully characterize processes of anticipation, it is necessary to pay attention to the relations between different practices and their effects. For this reason, I introduce in this last section the notion of assemblage, to account for how different practices come together among a multiplicity of elements, and how they influence each other and create joint effects. I use this notion as a heuristic to account for the multiplicities of practices involved in anticipation, their different contexts and the relations that emerge from them. Future expectations, as a dynamic phenomenon – such as hypes - can be understood as an anticipatory assemblage, a dynamic process that develops over time, in which local activities lead to global effects. Such is the case of both graphene and 3D printing, which are technologies that are currently going through a hype phase, yet the types of actors, practices and logics that characterize these hypes differ. However, despite these two fields being in principle substantially different, it is possible to recognize some common dynamics.

To understand this apparent conundrum, I focus on two aspects of assemblages: the first one is its reference to a set of heterogeneous elements that is brought together, which is constantly reenacted and has performative effects. The second aspect is that this specific arrangement can be found in various contexts, local and global, but that it is more than a pattern, because its structure is not given but constantly rearranged. Along these lines, one can think that hypes are the result of a set of expectations, practices, technologies and others that are brought together, partly because of the strategic activities of actors, but largely as a result of an arrangement of stabilized anticipatory practices that shape the future in specific and recurrent ways. A hype is both a local and a global phenomenon; it is the result of strategic and specific actions with local implications but also global and aggregated effects.

The notion of assemblage, rooted in the concept of *agencement* as introduced by Deleuze & Guattari (1988) stresses the way in which heterogeneous elements are brought together to generate effects that are more than the sum of its parts (DeLanda, 2006).[27] It is a way to go beyond the agency/structure dualism, and instead focus on how "the social" as a whole emerges as a result of the coming together – or assembling – of its parts (Latour, 2005). Because of its focus on action as embedded in a network, an assemblage can be essentially seen as a theory of practices which stresses that relations within the assemblage are not given, but made and remade through practices (Ong, 2014). This is a result of contingency but also of the reflexive action of actors (Michel Callon, 2007), and it is thus necessary to study the practical work required to build an assemblage (Bueger, 2014).

In these terms, we can think for example of the way in which different anticipatory practices across science, policy and industry are assembled to produce the "graphene hype". Scientific actors voice expectations through practices such as high profile scientific publications, conferences and grant applications, which are supported by policy actors. These expectations are translated into a language that relates to economic growth and societal impact, which results in opportunities and the creation of protected spaces. This brings in industrial actors with their own dynamics of market creation, who in turn translate expectations into values for future markets and opportunities for investment. In this process, expectations are circulated, translated and contested across different actor groups, a process in which a variety of anticipatory practices are deployed.

More than just an arrangement of practices, the notion of assemblage refers to the performativity of a particular set of practices. Callon (2007) uses this notion to explain in particular how the academic field of economics performs the economy. He shows how a statement, or the formula of a theory and "the world" mutually adjust – or co-produce each other, in a process that is recursive, contingent and reflexive. Similarly, an anticipatory assemblage has a performative effect on a technology, as collective expectations align to

27 Assemblage theory is a complex body of work; I do not use all the conceptual framework of assemblage theory as developed for example in the work of DeLanda (2006). Instead, I use the notion of assemblage as a heuristic to position and guide other elements of my analysis.

and co-produce the world to which they refer to (Konrad, 2006b). This assemblage fulfills specific functions, helping to generate a specific order in the world, which is constantly adjusted. Hypes fulfill the social function of bringing together actors to take high risks that otherwise would not be taken individually (van Lente et al., 2013). From this perspective, it is possible to consider the Graphene Flagship as a concrete result of the hype on graphene. In this case, a set of anticipatory practices aligned and coordinated scientific, industry and policy actors – and their expectations – into a large-scale project with the aim of profiting from the promises of graphene.

The second characteristic of assemblages that I refer to is that assemblages happen both locally and globally, thus transcending different spaces at the same time as they create connections between them. This dimension has been introduced through the notion of global assemblage (Collier & Ong, 2005) which refers to global forms of techno-science, expert systems or economic rationalism that operate at a transnational level and can be found in diverging (cultural and geographical) contexts.[28] In a similar way, while expectations about a technology are generalized and shared by different actor groups, the way and practices in which they are performed and their effect change in each case. For example, hypes take place across different actors' groups and institutional settings. The promises of a technology are often voiced in different spaces, with each space having its own ways and practices to articulate and receive these expectations. While the voicing of an expectation happens locally, in specific practices, some of these practices can have global effect and can translate the effects of an expectation beyond the particular setting in which they are embedded. This is, for example, the way the consultancy organization *Cientifica* characterizes the graphene hype. In a 2013 report, they introduce what they call typical "nanomaterial hype". The latter originates in academia, moves into the corporate domain and then to financial actors. As a cumulative effect, a sort of bubble is created, which then "bursts" and provokes disappointment (Cientifica, 2013). Expectations move and are translated across different spaces, creating linkages between them. The resulting effect is more than the sum of the individual dynamics of each space, and has an effect on each of them.

Finally and consequently, I introduce here the notion of *space* to refer to a specific arrangement of actors, practices, rules and institutions, such as science, industry, the financial sector, etc.; or institutionalized socio-technical configurations that are characteristic of

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28 These assemblages are constituted by a series of what they call "reflexive practices" which include technological, political and ethical forms to organize social life. These practices are translated into multiple contexts, replicating the assemblage in different locations at the same time. The global character of the assemblage is largely provided by the technical systems that compose it – calculations, models, etc. (Prince, 2012). This universality means that the assemblage is decontextualized and recontextualized, having the ability to move through diverse social and cultural situations in a way in which its functions and effects are maintained. This is not to say that an assemblage is something that occurs "locally" or the result of structural forces. Rather, it is "the product of multiple determinations that are not reducible to a single logic" (Collier & Ong 2005: pg.12) as the forms within the assemblage are always shifting.

a certain actor group and can be recognizable as such. Space in this respect is more than a reference to a spatial and temporal configuration, and more than just a metaphor for a particular type of social dynamics. Spaces have dynamics of their own, their own rules and structure (Rip & Joly, 2012)[29]; they can be considered as a particular type of assemblages themselves, because they are configured by a set of heterogeneous elements, and are constantly reconfigured through the interaction with other assemblages.

The concept of space refers to the concrete spatiality[30] of an assemblage as well as its ability to produce and sustain new spaces.[31] In that sense, the space is a property of the assemblage and it is at the same time produced by it. For example, chapter 5 shows that in the case of consumer 3D printers, Additive Manufacturing technologies, underpinning 3D printing, are an established technology for industrial prototyping – a well-established "industrial" space. In contrast, the consumer 3D printer was developed in a different space, constituted by hacker and maker communities. The development of the consumer 3D printer led to the emergence of hybrid spaces such as TechShops or FabLabs[32] where radical ideas and practices met and merge with market logics (Schneider, 2015).

After introducing the notions of assemblage and space, I will close this chapter by making explicit the relation between the elements that have been introduced earlier: expectations, performativity, governance, anticipatory practices and logics, assemblages and spaces. I should restate that my analytical focus is on practices and sets of practices as a means to understand performativity of expectations locally and globally and its relation to governance. In this context, the notions of assemblage and space are used as a heuristic tool to make sense of practices that come together. As shown in 2, this framework has two analytical foci: first, it addresses anticipatory practices at the local level, as instances for the creation, shaping, mobilization and contestation of expectations. The practices that do or

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29 They argue that spaces are not just a metaphor, but that they actually have dynamics of their own and specific characteristics: there is a certain spatiality where actors can "move about" (and which allows room for deliberation and experimentation; the space itself has boundaries that are more or less permeable; and last, it has an internal structure given by the rules of interaction inside the space. Spaces are both stabilized and emergent, they are constantly changing but they are at the same time, easily recognizable arenas of interaction.

30 By spatiality I want to make explicit that assemblages are not just discursive, but that they enable certain social interactions through technologies, devices, rules and institutions, shaping the social – and even the physical, as argued by Anderson (2010, 2012) –world.

31 Space here does not only refer to a geographical space, but it can take the form of any platform in which a set of actors come together. This includes institutions (both explicit such as a municipality, or more abstract such as "science") as well as online spaces, emergent platforms, etc.

32 Fablabs and Techshops, and other types or makerspaces are shared machine facilities that resemble industrial production facilities, but they are at small scale and open to the public. In these spaces people of diverse backgrounds an interest meet to fabricate what is of their own interest (Nascimento, 2014; Walter-Herrmann & Büching, 2014)

do not take place are the result of particular (combination) of logics. In this context, there is a reflexive relation between expectations and practices, which is located in a specific space and at the same time reshapes these spaces. The second analytical focus is on what happens when practices come together. Anticipatory practices do not act in isolation, they act in bundles of practices. Furthermore, they can move between different spaces and translate expectations from one space to another and from the local to the global. Such a dynamic can be conceptualized as an anticipatory assemblage, which I describe in relation to the practices and expectations that compose it, and which are brought together to make "the future" actionable and anticipation possible.

Through this approach, I introduce to the Sociology of Expectations a perspective that stresses the way in which expectations are built, the agency of actors, as well as the role of materiality in producing certain expectations dynamics. While such an approach is implicit in the basic assumptions of the sociology of expectations (Borup et al., 2006; van Lente, 1993), I introduce an analytical framework explicitly tailored to empirically capture this phenomenon.

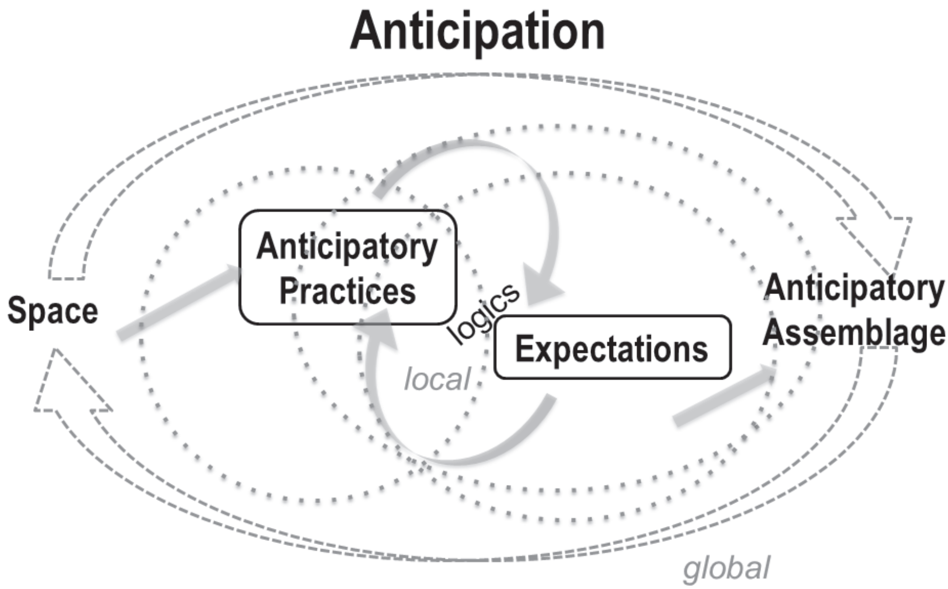

Figure 2: Anticipatory Assemblages and spaces. The notion of assemblage accounts for the multiple ways in which anticipatory practices and expectations are arranged, and their performative effects. These assemblages have effects locally, but as they occur in different spaces, they also show global effects as the relations between these spaces.

3. Research Design

In this chapter I explain the research design used to analyze anticipation in emerging technologies. I studied the practices in which expectations are created, shaped and circulated, and which ultimately lead to phenomena such as hypes. These anticipatory practices are conceptualized as practices that shape expectations about a technological field. While practices can differ depending on the space in which they take place (scientific publishing, policy, laboratories, financial markets, etc.), they are nonetheless interrelated. In this context, my guiding research question relates to the different types of anticipatory practices that can be found in different techno-scientific fields and their corresponding spaces, and their performative effects as individual practices and in relation to each other. I have phrased this question as What kind of practices shape processes of anticipation in emergent technologies, and what are their performative effects?

To answer this question, I chose a case study approach, in order to study in detail the process of emergence of a new technology field and its relation to expectations. Case studies are in-depth analyses which maintain a certain degree of open-endedness in relation to their boundaries. They encompass the collection of a dense set of material and a diversity of research methods (Morgan, 2012). My research aim is to characterize and study a diversity of forms of anticipation in emerging technologies. For this reason, I conducted two case studies that capture this diversity and which were analyzed using a grounded theory methodology. The "units" of these case studies are two emergent technology fields, which I delimited geographically to Europe and the United States.

In order to capture this diversity, I used a heuristic for the selection of the two cases based on the notions of *regime of economics of techno-scientific promises (ETP)* and *regime of collective experimentation (CE)*, as introduced in chapter 2 (Felt & Wynne, 2007; Joly, 2010). These notions refer to two distinctive forms of anticipation that are relevant for emergent technologies today, which in theory involve different practices. As I will explain in the following section, these two categories represent two ideal types in which techno-science is configured, with different roles for expectations, different anticipatory practices and different forms of anticipatory governance.

3.1. Selection and description of cases

Based on the conceptual framework, I developed three criteria for the selection of relevant cases. These criteria refer to the type of technology (i), the expectation dynamics (ii) and the existing configuration of the field (iii).

Criterion (i) delimits possible cases to fields that can be labeled as emergent technologies, or emergent techno-science. Rotolo *et al*. (2015) define an emergent technology as,

> a radically novel and relatively *fast growing technology* characterized by a certain degree of coherence persisting over time and with the *potential* to exert a considerable *impact* on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, *lies in the future* and so in the emergence phase is still somewhat *uncertain and ambiguous* (ibid: pg.1828, emphasis added).

This definition points toward technologies with great potential, but still in a phase of rapid emergence and with many uncertainties. What can be observed for these not-yet defined technologies is patterns and emergent paths, particularly through expectations, promises and projected futures, which are the major anchor points of these fields (van Merkerk & van Lente, 2008). Graphene and 3D printing can be considered emerging technologies because they are still in a high phase of growth, development and change, characterized by high and heterogeneous promises and significant uncertainties. This phase of growth can be linked with the empirical phenomenon of hypes, the next criterion.

Criterion (ii) refers to the dynamics of expectations. Many emergent technologies go through a phase of overpromising and strong attention known as hype. I argue that both graphene and 3D printing are currently going through a phase of hype. Assessments of hype are often based on discourse and media attention.[33] While I did not conduct an in-depth qualitative discursive analysis of expectations for each case, a number of quantitative indicators of attention (internet searchers, scientific publications and media) support the claim that these technologies are going through a hype phase. For each quantitative analyses of each case, I used the terms “graphene” and “3D printing” respectively, in three different databases[34] between the years 2004 -2014. I used the following databases: Google for general attention, Scopus for scientific publications and Lexis Nexis for general media. This time frame was chosen because important events took place between these dates: in 2004 graphene was discovered, and it is also around the time the RepRap project began (Bowyer, 2007).

A Google Trend[35] analysis comparing both terms shows that searches have increased during recent years in a similar manner, although the attention to 3D printing is higher than

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33 A common assessment of hype is to look at media attention, both in terms of numbers (how many times a term is referred/time) and in terms of the content of expectations (optimistic/critical) (Konrad et al., 2012; van Lente et al., 2013)

34 In the case of scientific publications I also included the term Additive Manufacturing, since 3D printing is a popular term, not a technical one.

35 Google Trends shows how often a term has been searched for in relation to the total search volume.

graphene, which is slightly decreasing (3). Similarly, the number of scientific publications indexed in Scopus has increased exponentially through the years. For graphene an exponential growth was observed following the years of its discovery and until 2010-2011 (Hui et al., 2011; Shapira et al., 2012; Winnink, 2012), followed by a linear but sustained growth in the number of research papers. Comparing the results for the Scopus database, the relevance of graphene for the scientific community is much higher than 3D printing (4). This might be due to the fact that 3D printing is still largely an industrial field, while graphene has developed in the scientific domain of condensed matter physics and nanotechnology.[36] Lastly, an analysis of references to each of these terms in all English-speaking media available at the Lexis-Nexis database,[37] shows an exponential growth in news items referring to graphene and 3D printing (5). These three quantitative indicators show an increase in attention, which qualifies as a hype.

In addition, I rely on actors' accounts of the field to assess this hype phase. For both graphene and 3D printing, the idea of an ongoing hype has been suggested already since 2012. In particular, consultancies such as IDTechEx, Lux Research and Gartner Group have claimed around 2013 that graphene and 3D printing are at the peak of the hype (Gartner, 2014; Ghaffarzadeh, 2013; Kozarsky, 2013), a diagnosis that is shared by other actors. My claim that these technologies are going through a phase of hype is based on this set of indications. However, my intention is not to further characterize the changes over time in types of promises and concerns that compose these hypes in detail, but rather their constituent practices and dynamics.

Criterion (iii) refers to the configuration of the field. This criterion is what makes these cases different and relevant to understanding different forms of anticipation. In Chapter 2 I have introduced the notions of *regime of economics of techno-scientific promises* (ETP) and *regime of collective experimentation* (CE) (Felt & Wynne, 2007; Joly, 2010). Graphene represents a case of ETP because it is closely linked to a scientific discovery attached to big promises of economic and societal impact, leading to important public and private investment and the need to control undesirable consequences (e.g. risk). In contrast, 3D printing stands for the second regime (CE), because the development of this field has been largely connected with grassroots innovations in which user communities have taken up established technologies, and reinvented their socio-technical structure to adapt them to their needs. In this respect, the field is about the experimentation (e.g. tinkering) with

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36 Only recently the research community has started to engage more systematically with research in 3D printing. This is partly a consequence of the big attention this field has had and the search for new materials. Additionally, technologies under the name of bio-3D printing are being used to produce living tissue, which has mobilized the attention of the scientific community.

37 The Lexis-Nexis database includes all major English-speaking newspaper, business news, and related publications.

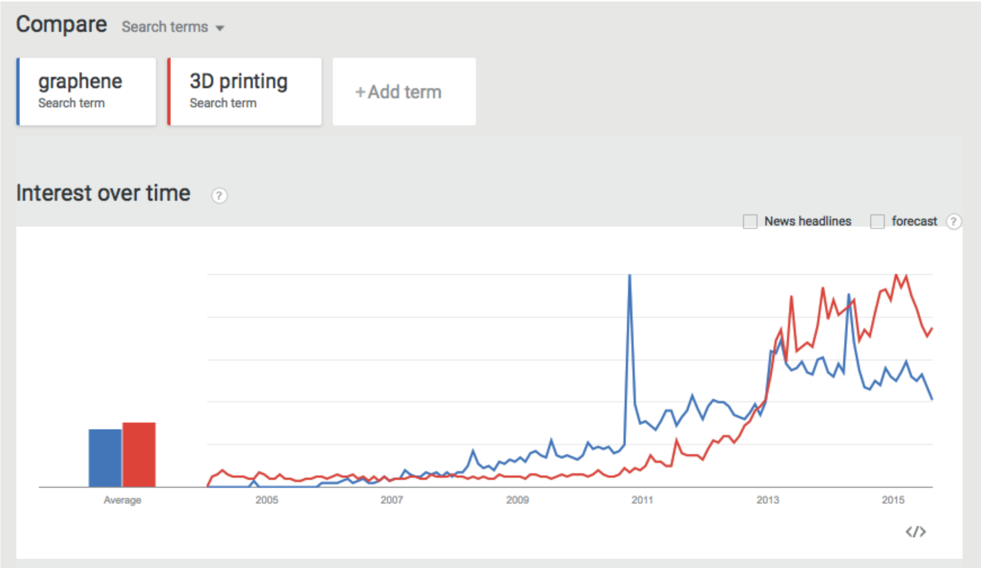


Figure 3: Google Trends graph, search terms "graphene" (blue) and "3D printing" (red). In both cases there is an increase in searches, particularly from 2010 onwards. Generated by the author on August 2015, under license of use for educational purposes by Google.[38]

machines and their embedding in society.

It is important to note that my approach is not a comparative one, in which case studies are considered in relation to given variables, and which requires a certain degree of standardization and consistency to make the comparison possible (Flick 2009). Instead, the way I approach these two cases is as if they were self-contained case studies. These two cases can be considered paradigmatic: cases which highlight more general characteristics of the phenomenon in question, operating as a reference point for the development of theory (Flyvbjerg, 2011). Paradigmatic cases are useful since my interest is not only to empirically answer my research question, but also to develop an analytical perspective for understanding anticipation as a socio-material practice. Therefore, the case selection aims to capture situations that represent different forms of engagement with the future in emergent techno-science. In other words, the two cases do not represent two opposing or two extreme forms of anticipation; they have some similarities but also important differences. Such differences allow me to capture a wide range of anticipatory practices. Second,

[38] For permission for using graphics generated by Google, see http://www.google.com/permissions/using-product-graphics.html

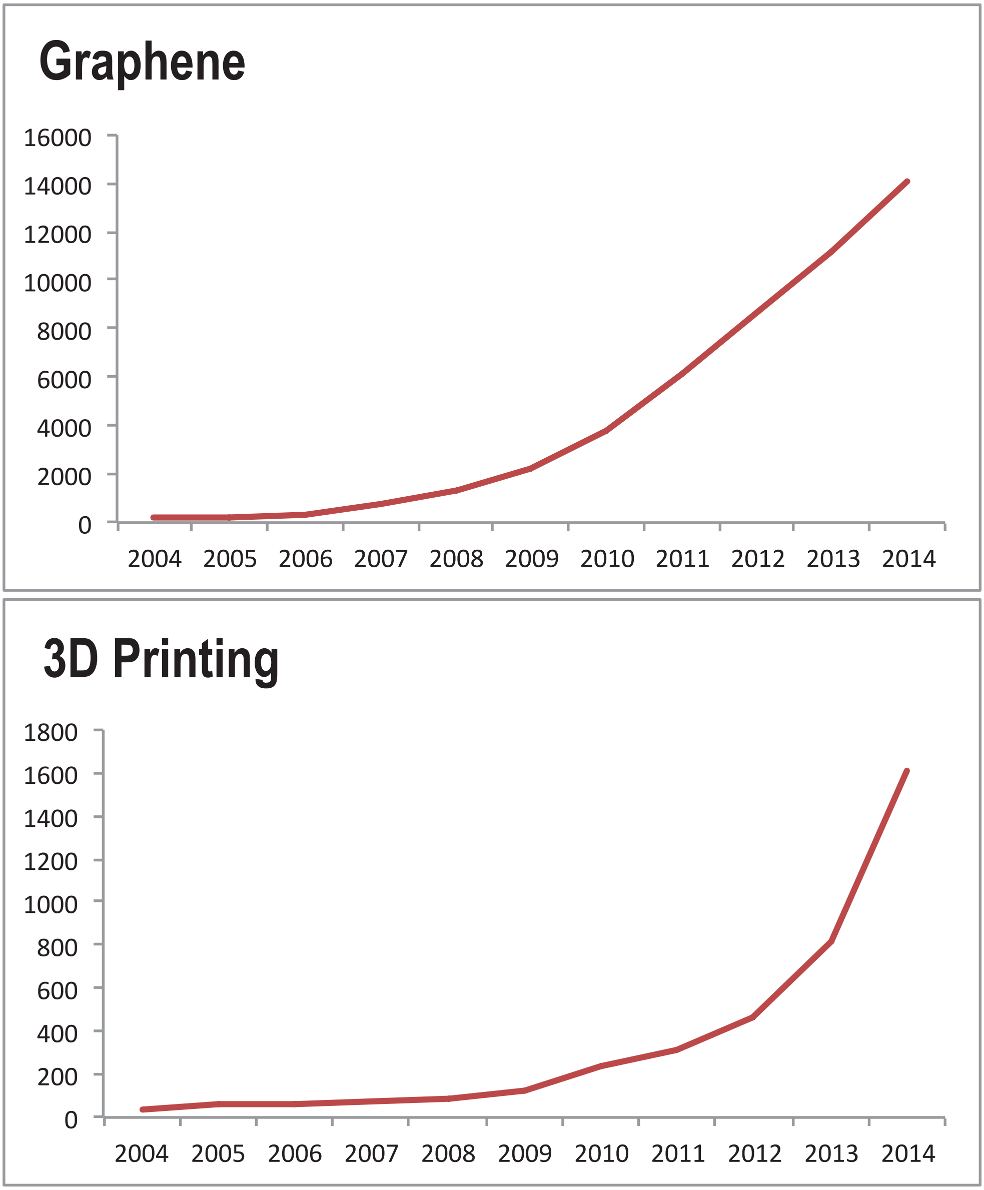
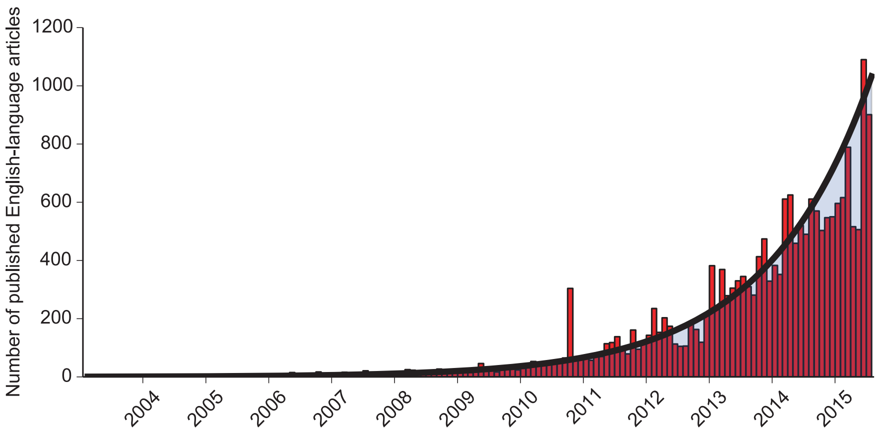


Figure 4: Number of Scientific Publications (2004-2014) for graphene and 3D printing. It is important to note that the number of articles in graphene (approx. 15,000) is substantially higher than the one for 3D printing. The graphs were generated by the author (August 2015) using the Scopus database.

Graphene



3D Printing

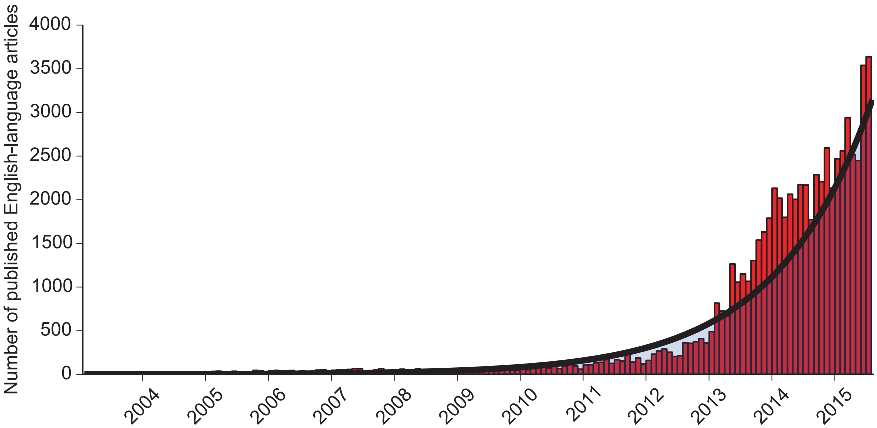


Figure 5: Media references to graphene and 3D printing (2004-2015). In both cases there is an exponential increase. Generated using Lexis-Nexis database by extracting the number of hits for "all English news" using the terms "graphene" and "3D printing", using the option "group duplicates: moderate similarity" which removes those hits that are similar. Graphs by Stephen Sinclair, August 2015

my case selection enables me to assess how certain aspects such as the structure of a field, types of actors, institutions, publics, and technologies themselves, which are different for ETP and CE, affect the practices that take place.

The two cases selected were approached in slightly different ways because of the different empirical characteristics of each field, which I detail in the following section. In general, the graphene field presents "conventional" anticipatory practices such as roadmaps; it is a relatively small and centralized field with a clear core group of actors. In contrast, for 3D printing, the field itself is larger as it has developed both in the industrial domain and among diverse communities of makers and hackers. It includes both explicit (such as industrial roadmaps) and implicit forms of anticipation. Because my interest was to map different anticipatory practices, I decided to focus on those implicit anticipatory practices in 3D printing that could not be observed in graphene, such as the development of prototypes or tentative governance arrangements of technology. Second, since the 3D printing field is composed of a higher number of actors, I decided to focus on a more specific aspect of the technology, instead of attempting to map the whole field. In fact, and in contrast to graphene, there is extensive research in socio-technical and innovation aspects of 3D printing (Potstada et al. in press).[39] Therefore, in order to produce relevant research insights it was necessary to focus on less explored areas, such as the activities of consumer 3D printing companies and their relation with activists groups (1).

3.1.1. Graphene

Graphene is a carbon based, two-dimensional material first isolated in 2004 by two Russian scientists located at Manchester University, Andre Geim and Konstantin Novoselov (6). They were granted the Nobel Prize in Physics for this discovery in 2010. For the physics community, this material became a new model of study because of its properties that enable quantum-measurements at room temperature (Katsnelson & Novoselov, 2007). These properties were described in an earlier paper in Nature (Novoselov et al., 2005) which was so influential that – at least according to some scholars like Winnink (2012)[40] – led to an exponential rise in graphene research. In fact, the impact of the work of Geim and Novoselov is reflected by the number of citations their early research papers have, among the most cited in history for Science and Nature. The Science paper "Electric field effect in

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39 There is a dedicated journal called 3D printing and Additive Manufacturing, which includes technological, market and social aspects http://www.liebertpub.com/overview/3d-printing-and-additive-manufacturing/621/

40 "We conclude that after the accumulation of theoretical knowledge about graphene for over 50 years the publication of the Novoselov paper had an immediate and large impact on the R&D community: resulting in a sharp rise in the number of scholarly publications and at the same time an increase in the number of filings for patent applications." (Winnik, 2012; pg.1)

atomically thin carbon films" (Novoselov et al., 2004) has been cited 19,671 times and it is the 3rd most cited paper of this journal. The Nature paper "The rise of graphene" (Geim & Novoselov, 2007) has been cited 14,447 times and it is 4th most cited paper in this journal.[41] This is particularly striking for such recent papers, since the other research papers equally cited are much older. There has been much discussion in relation to the sources of such attention, but it is important to note that graphene emerged as the latest of a family of carbon nanomaterials that was easy to fabricate in the lab through the scotch-tape method, in contrast to its predecessors.[42] Quickly, this material became very popular for studies in condensed matter physics and related areas. This exponential growth was accompanied by promises about potential applications enabled by graphene. One of the earliest of these promises is the use of graphene as a replacement for silicon in semiconductors, in the context of Moore's law, the "guiding expectation" of the semiconductor industry (as referred in Chapter 2). In fact, the promises of graphene in electronics have been shaping the field from early on (Geim & Novoselov, 2007).

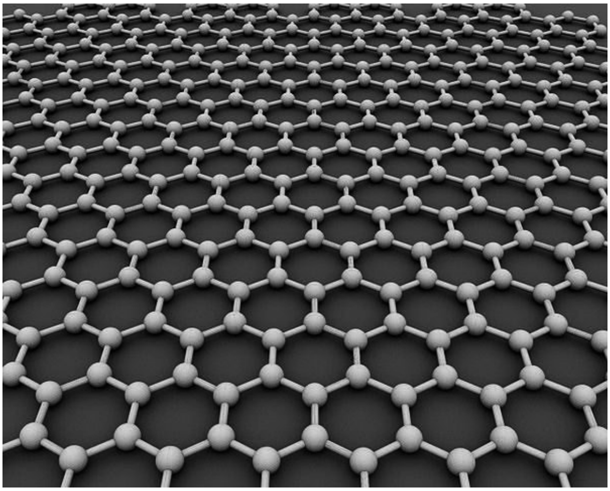

Figure 6: How a sheet of 2D-graphene looks theoretically. Source: Wikicommons, under license Creative Commons

41 In both cases, according to the Scopus database

42 The impact of the work of Geim and Novoselov in the graphene field is summarized in this quote "At the many conferences where graphene work was reported, the Geim-Novoselov team maintained their leadership position in this fast moving field, by continually generating new, exciting results. It was the high quality and impact of these publications and public presentations that made an indelible mark on the graphene field and on science more generally. This continued leadership has been very impressive to the science community." (Dresselhaus & Araujo 2010; pg.11)

Moore's law, formulated in 1965 by Gordon Moore, claims that the number of transistors in an integrated circuit will continue to double approximately every two years, resulting in a reduction of manufacturing cost per function that enables the production of more complex circuits (Cogez, Le Masson, & Weil, 2010). This translates into an exponential growth in the number of transistors, as illustrated in the well-known Moore's law curve (7). This figure is important as a material embodiment of Moore's law, because it has served as “the technological barometer” against which different industry players have set the pace and strategy for long term development of the industry (Barnett, Starbuck, & Pant, 2003). A disruption of the trend indicated by the figure would seem to imply a revocation of Moore's law.

Since the early 1990's, the work of sustaining the pace predicted by Moore's law has been institutionalized through the International Technology Roadmap for Semiconductors (ITRS), which is a specific and highly coordinated form of anticipation. This roadmap is a way of managing the continuation of the trend, which is characterized by a struggle for continuity under a perpetual revolution, and this requires particular innovation strategies of companies to keep up with the expectations (Choi & Mody, 2009; Le Masson et al., 2012). The objective of the ITRS is to “ensure cost-effective advancements in the performance of the integrated circuit and the advanced products and applications that employ such devices, thereby continuing with the health and success of the industry” (http://www.itrs.net/about.html). Or, as the 1994 definition states, “The Roadmap is analogous to paved roads of proven technology, unimproved roads of alternative technologies, footpaths towards new technologies, and innovative trails yet to be blazed” (Semiconductor Industry Association 1994, as quoted by Cogez et al. 2010). The biannual predictions of the ITRS result in a roadmap. The roadmap gives the best current estimate for the future of the industry between 2 to 15 years. The document is explicit about the feasibility and agreement over specific goals. In recent years, the roadmap has started to include prospects about emergent technologies that could be useful to the industry and are worth exploring. These are framed under the names of Emergent Research Materials (ERM) and Emerging Research Design (ERD). Graphene was introduced in the roadmap under ERM in 2007, as a technology with interesting possibilities worth exploring. Particularly, graphene was framed in relation to those technologies that will come after the silicon-based transistor. This is known as “the end(s) of Moore's law”: since its inception there have been predictions that it will come to an end. Many industry leaders acknowledge that there is a point when the type of growth predicted by Moore's law will not be possible anymore, and the use of a new technology - different from silicon-based transistors - will become necessary.

The alleged ends of Moore's law have been particularly effective in pushing research in new materials. This is the case of nanotechnology as a field that was largely funded as

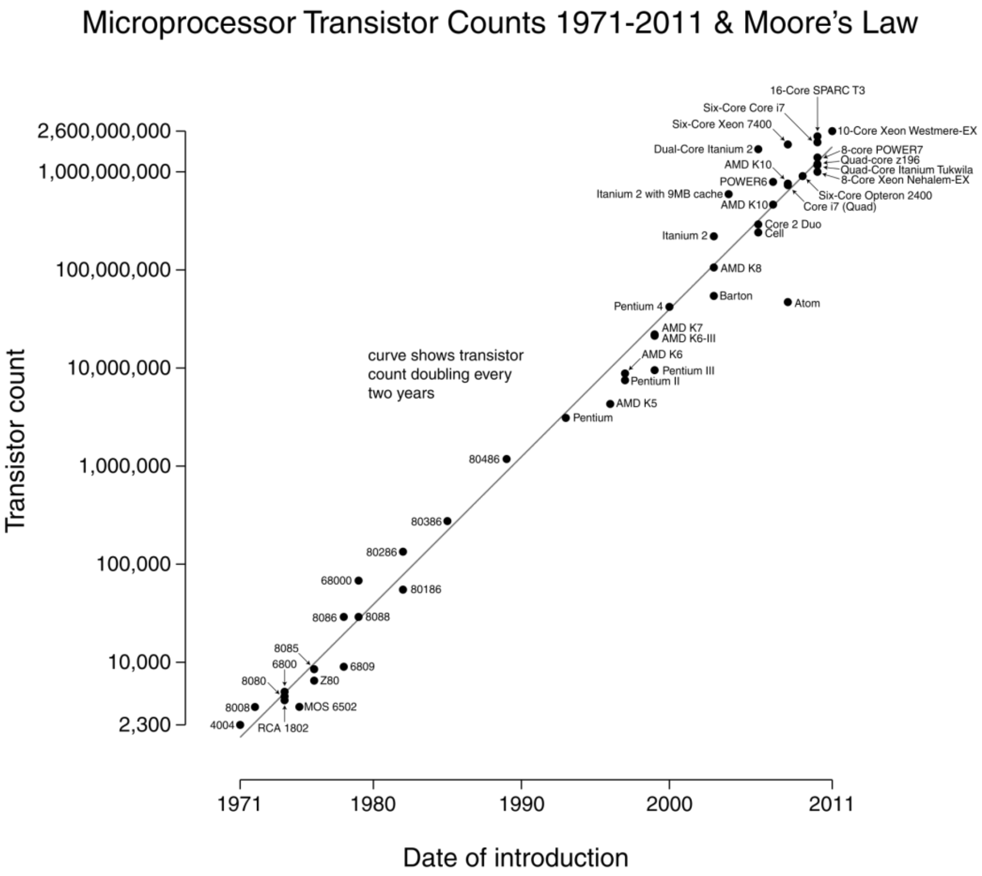

Figure 7: Moore's law until 2011 (source: Wikicommons under Creative Commons license)

a means for a new type of electronics (McCray, 2005).[43] The history of nanotechnology is incomplete if it neglects the microelectronics industry; in fact, many of these materials called "orphans of microelectronics" have constituted the nanotechnology field (Choi & Mody, 2009). Over and over, new materials, including graphene, have been presented as the natural successors of silicon, which still remains the dominant material for transistors (Spinardi, 2012). However, the large investments made into developing new materials have contributed to the development of other types of electronics applications, including high-frequency chips and optoelectronics, as well as new approaches such as molecular electronics and spintronics (Choi & Mody, 2009).

It is against this background that graphene and its promises have developed, following the development of other carbon-based nanomaterials. In fact, since its inception graphene has been compared to and benchmarked against carbon nanotubes (Kozarsky, 2013; Van Noorden, 2006). There are many similarities between the two materials: when carbon nanotubes were discovered, there was a strong enthusiasm based on the interesting properties of the material. Such enthusiasm triggered efforts to find an efficient and cost-effective way of producing them, yet without a clear application to begin with. Consultants have referred to successive investment activities as a bubble, since many newly founded nanotube companies failed and had to exit the business (Biondi, 2013; Cientifica, 2013; Kozarsky, 2015). To date, carbon nanotubes have not fulfilled their original promise.

Graphene (which is in principle an unfolded, 2D version of a carbon nanotube) has been framed as the material that will actually enable these promises to come true (Arthur et al., 2012). However, to date graphene seems to have gone through a similar hype as other carbon materials (Peplow, 2015). There have been numerous public and private investments to develop and produce graphene at a large scale. Korea and China have invested heavily in graphene, with the largest production facilities and the largest number of patents (IPO, 2013). In Europe, a public investment of 1 billion euro (for 10 years) has been launched under the name of Graphene Flagship (http://graphene-flagship.eu/). This research project is a European-scale undertaking that brings together academic and industrial research with the purpose of developing the economic and social potential of graphene and associated 2D materials. I will describe this project in detail in Chapter 4.

In addition to these public investments, private actors have also engaged in the development of graphene. As of 2015, there are more than 100 companies listing among their activities in the development of graphene or graphene-enabled applications (http://www.graphenetracker.com/companies/). This includes both large electronics and chemical companies such as Samsung, IBM and BASF, and small start-ups from Europe, United States

43 One consequence of this is the International Nanotechnology Conference on Communication and Cooperation. This is an annual event where leaders from the semiconductor industry and nanotechnology research meet to discuss the long-term future of the industry, looking at the promises and potential risks of nanotechnology, particularly in the context of electronics. See for example http://inc11.org/About_INC.html.

and Asia. It is indeed in Asia, particularly in China and Korea, where the largest number of graphene companies has been created, and that holds the largest capacity of production of graphene (Peplow, 2015). This emergent market has promoted the entrance of consultancy organizations (to which I refer in Chapter 6) and the creation of industry associations such as the Graphene Stakeholders Association (http://www.graphenestakeholders.org/). Both in public and private investments, the development of graphene has been framed in terms of "responsible" development and innovation. This translates specifically to taking into consideration the health and environmental risks, and the development of adequate regulation and necessary standards.

As I have described, the graphene field is an emergent area originating from research in condensed matter physics, and largely a scientific and technological field connected to the development of nanotechnology. Public investments such as the European Flagship project have brought the interests of industry, researchers and market actors together to develop the potential of this material. Despite these efforts, graphene remains a research area with a small but still promissory market.

3.1.2. 3D printing

"3D printing" is the name given to a range of manufacturing technologies that produce objects additively (layer by layer) instead of by subtracting material from a substrate, as in the case of conventional manufacturing. The technology, originally called Rapid Prototyping, has been used for about 30 years for the development of industrial and architecture prototypes. Two American multinationals have historically dominated this market: Stratasys and 3D Systems. However, until the mid 2000's, the market remained limited to these prototyping applications and niche markets such as the development of hearing aids.[44]

In recent years the industry has differentiated two areas of development, Additive Manufacturing (AM) and 3D printing (3DP). The former refers to technologies oriented towards industrial production of customized objects, with large capital investment, and the latter to the development of consumer machines for the production of 3D printed objects through more accessible additive methods at home or in a small company (Hague & Reeves, 2013). While these two areas of development share a technological basis and involve similar actors, they show different dynamics. In this dissertation, I refer to the development of the consumer 3D printer (3DP) when I speak of 3D printing as a field. It is important to note that what differentiates these two areas is in terms of business models and the scale of the technology; but the types of technologies and materials used in both cases are similar, thus there is a common space for innovation . In fact, the biggest difference comes from the way in which different publics identify with the promises about

44 The development of hearing aids has been one of the first success stories of 3D printing, in which customized items could be produced at much lower cost thanks to the technology.

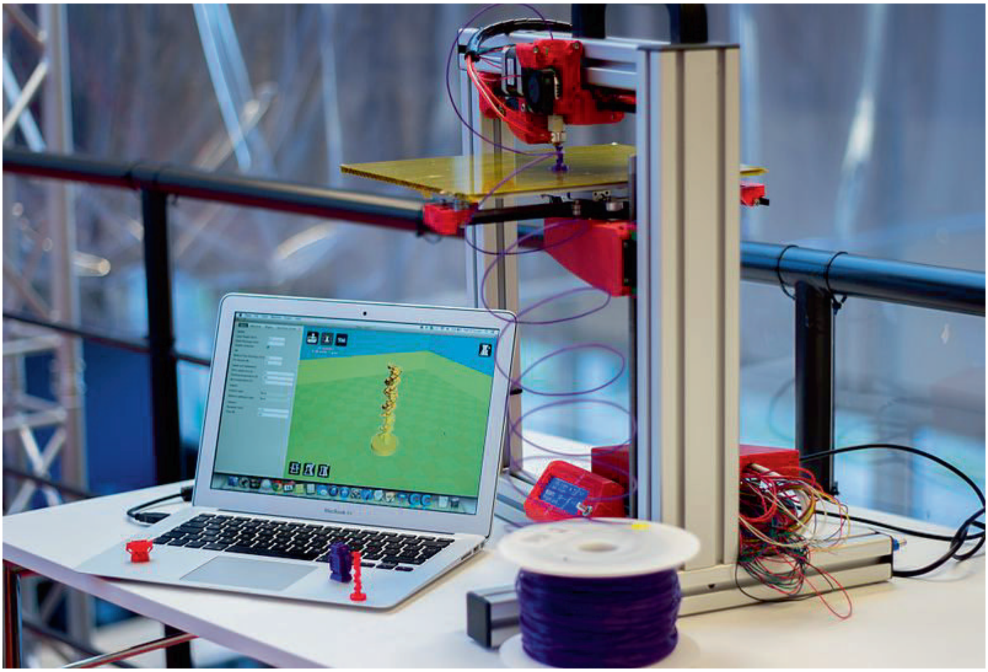

Figure 8: Felix 3D printer set up (http://www.felixprinters.com/). This includes a model of the 3D printed object, and an FDM machine with its material supply (plastic). Source: wikicommons, under license Creative Commons.

empowerment of 3D printing (Fordyce, 2015). I chose to focus on consumer 3D printers or "3D printing" because in this particular case, the development of machines at a user's scale has been largely the work of maker and user communities, which resembles a *regime of collective experimentation*.

It is important to note that there are different technologies that fall under the label of 3D printing - they may for example operate under the same design principle, but use different materials (plastic, metal, etc.). These different technologies have distinctive technological affordances and limitations. The most common is FDM (fuse deposition modeling), in which a plastic wire is heated up and extruded to create 3D forms. This is the basis of many consumer 3D printers (8). Other important fabrication mechanisms are SLA (stereolitography) that work with a photopolymerization mechanism, and SLM (selective laser melting) that enables metal printing.

The development of the consumer 3D printing did not originate in the industrial domain, but in maker communities interested in developing the potential of the technology to empower users. Particularly salient is the RepRap project which aimed at producing an open source 3D printer able to reproduce itself - hence the RepRap "Replicating Rapid Prototype" title (Bowyer, 2014). This project was initiated by Adrian Bowyer in 2004, who was inspired by ideas of self-dependency and self-sustenance that will "bring down capitalism" – as framed by the newspaper the Guardian, echoing Bowyer's claims (Randerson, 2006). Since its inception, the *consumer 3D printer* has been accompanied by grand visions and ideas. In particular, 3D printing has been named as the technology that will trigger the "third industrial revolution", which also refers to bring back manufacturing capacity to Europe from Asia (C. Anderson, 2012; Rifkin, 2011).[45] In this vision, a radical vision of the future is achieved not through revolutions or social revolt, but by the development of technologies that enable new forms of production, which ultimately change means of ownership and power relations (Söderberg, 2014).

As an open-hardware project, the development of the RepRap spurred collaborative and open innovation across a community of hackers and makers across the world, rapidly spreading the promises of the technology (de Bruijn, 2010). This form of collaboration is common to open-source communities, in which ideas are discussed alongside the development of technical objects (Kelty, 2008). The result of such collaboration was a first desktop size 3D printing accessible at a much lower cost than the existing industrial 3D printing machines. As a consequence, it opened up the field to a completely new market, thus extending it beyond the existing prototyping industrial applications. This new market came with an inherent tension built into it: while there is a rebellious rhetoric framed as a political project, it contrasts with a practice (in makerspaces and related communities) that is closely related to entrepreneurship and capitalism (Maxigas & Troxler, 2014). This means that while ideas, visions and narratives of the future are radical, practices that anticipate this future nonetheless relate closely to incumbent forms of production, and do not challenge them.

More than a new machine, what the development of various forms of consumer 3D printers has achieved up to now is to install in the collective imagination a vision of empowerment, which has been used indistinctively by both maker communities *and* companies. This vision has been spread through various forms of media, including blogs, major publications, books and TED talk presentations. Such increased attention has been characterized as a "hype" by actors in the field, because according to them the promises are decontextualized and far beyond the actual possibilities of the technology (Bass, 2013).

Central to the development of the RepRap project has been the idea of developing collaborative, open source hardware (de Bruijn, 2010; Söderberg & Daoud, 2011). This idea,

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45 The promise of bringing back manufacturing has been particularly important in policy circles. For example, in the State of the Union 2013, president Barack Obama spoke about 3D printing in the context of creating new Jobs for Americans.

while assuming slightly different forms over time, is still relevant for many 3D printing enthusiasts, and it is actively discussed in the field. An example of this is the recent acquisition by Stratasys of Makerbot, one of the first companies that commercially sold consumer 3D printers. Makerbot spun off from the RepRap project in 2009 and quickly became the market leader of desktop 3D printers. The company created the website Thingiverse, an online community for sharing user-generated 3D designs that could be used in a consumer 3D printer (West & Kuk, 2014). This model of a company that produces consumer 3D printers with an associated site that generates content and networking possibilities for their users has been replicated many times around the world for those startups that want to find a niche in the field. When Makerbot was bought by Stratasys in 2013, they changed their original open source approach to a strategy in which proprietary technology became more relevant. This change was received with disappointment by many of its supporters. These communities have shifted their attention to other companies (such as the Dutch Ultimaker which is discussed in Chapter 5) while decreasing the relevance attributed to open source at all, which remains a contested issue in the field.

In relation to these developments, an increase of media attention to 3D printing is observed in 2013. While various reasons explain the increasing attention to the technology, one particular event drew the attention of general media: the online release of the files of the "Liberator," a 3D printed gun developed and promoted by Cody Wilson. Shortly following the release of the design files for this gun – which were downloaded more than 100,000 times – regulatory authorities and policy bodies questioned the safety and potential risks that 3D printing technologies entail (Record, Ginger_coons, Southwick, & Ratto, 2015). In many countries, including the Netherlands, this was also the actual trigger of a discussion of a future where 3D printing was a widespread technology, and of its societal impact.

Since this event, the attention for 3D printing and associated technologies has remained extremely high. As the technology has expanded from its initial roots in maker communities, challenges about what its configuration in society might be have become more explicit (Troxler, 2014). Nevertheless, the hype remains and the actual embedding of this technology in society is still in the making.

In summary, this emergent field is composed both of maker and user communities and of market actors, from established industries to startups. In this sense, it moves between different imagined socio-technical configurations, and different forms to anticipate it. Only recently, policy actors have more systematically engaged with the promises and risks of the technology, in response to concerns about safety (3D-printed gun) and copyright, as well as its promises and opportunities. Still, the field – particularly consumer 3D printers – remains largely detached from the scientific community. [46]

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46 An exception is what is known as bio 3D printing, which is a form to call new developments in tissue engineering which enable the production of living tissue such as organs. This technology still remains a promise since real production of functional tissue is not fully viable, but has gotten the attention of the

Table 1: Comparison between the two case studies

	Graphene	3D printing
General Field Characteristics	Scientific discovery turned into a promise, creating considerable attention from the scientific and technological community, particularly those related to nanotechnology.	30 year old industrial technology that was redesigned by users in order to adapt to the consumer scale.
Content of Expectations	New material with outstanding properties that could fuel a new wave of innovation, particularly in electronics.	A new mode of fabrication that could displace current manufacturing techniques, changing the geography of production and empowering users.
Actors and Spaces configuration	Strong presence of scientific actors; policy makers from EU related to the Graphene Flagship (not in the US); around 70 start-up companies, many of them university based; presence of technology consultants with a background in nanotechnology.	Two well-defined spaces: on the one hand, the industrial sector which has developed the technology under the label of Additive Manufacturing. Second, maker communities that have developed consumer 3D printers. In addition, there is an increasing presence of policy and regulatory actors, particularly in response to concerns.
Main Anticipatory Practices	Strong relation to micro and nanoelectronics, and their modes of coordination such as Moore's law. Also relevant is the circulation of expectations in high profile journals and practices of consultants such as market reports.	Promises are strongly embedded in the development of software and hardware; development of material objects that embody the promises and enable their circulation. In addition, conferences, speeches and workshops are also relevant.

3.2. Methods for Data Collection and Analysis

As I have described in the previous chapter, the core analytical focus of this research is anticipatory practices. The main research question *What kind of practices shape processes of anticipation in emerging technologies, and what are their performative effects?*, can be understood as shedding light onto the anticipatory practices that shape emergent fields, how they are arranged, and how they influence innovation processes. That is to say, the focus of this study is on practices in their context. Studying practices through ethnographic approaches in local settings (e.g.. the laboratory) has a long tradition in STS (Latour, 1987; Suchman et al., 1999). Anticipatory practices are often not just local practices, but rather complex arrangement of actors, technologies and expectations across different contexts during a certain period of time. For example, the development of a roadmap involves many other practices, such as collecting expert opinions, meetings, etc., which all contribute to the making of a roadmap. For this reason, the full complexity of these practices has to be reconstructed by tracing them through their components, materiality and effects. Following Shove et al. (2012), practices can be understood as a set of elements that are brought together when practices are enacted, and which leave certain traces and have specific effects. Thus, in order to reconstruct the past and ongoing dynamics of anticipatory practices, as well as their inter-relations and relations to expectations, I draw on a combination of methods and sources which capture these practices as part of discourse, materiality and in their active performance.

More specifically, I draw on four main sources of data: *documents* (from scientific publications, to media consultant reports and policy documents), *interviews* with actors from the field, *digital media* and *participant observation*. I followed a grounded theory approach in which a wide range of sources is used to alternate between data and theory (Suddaby, 2006). For this reason, I draw equally from each of these sources; this means, there is no concerted order such as starting with reviews, then interviews, etc. Instead, I reconsider every source in each round of research. This is because both the depth and breadth of my understanding of each field grew with each round of data collection and analysis. The number of rounds was determined by a point of saturation (where no relevant new insights were obtained by looking again into the data) and by the time constraints of each case (18 months for graphene and 14 months for 3D printing).

The first step was to become familiar with each of these fields. Thus, a first round was organized around scientific papers (for graphene, the most cited; for 3D printing, an important number of STS and media studies) published books, general media, and expert interviews. This was followed by several rounds of data collection and analysis. Each round lasted between 4 to 6 months, and included on average 8 interviews, one event and an extensive revision of different types of documents which varied between rounds. After each

research community.

round I transcribed, coded and analyzed the data, generating descriptions of my findings that were then used for the following round. The types of questions that were asked of the material varied from one round to the next; the interviews, for example, became more specific as I gained more knowledge about the position of each actor in the field.

This approach can be related to the notion of "moving about" in emergent domains (Robinson, 2010; te Kulve, 2011) which refers to a data collection strategy aimed at capturing and reconstructing ongoing dynamics. This approach combines "interviews, extensive desk research and visiting/participating in physical spaces (i.e. workshops, seminars, conferences and meetings) where ongoing developments are taking place" (Parandian 2012, pg.45), and which the researcher is able to embed him/herself into the field, to the point of being able of contributing to its shaping. Moving about requires the use of different data sources in order to capture a diverse set of activities of a diverse set of actors. The "moving about" approach has been developed in the context of CTA (Constructive Technology Assessment) and has the explicit aim of contributing and steering the development of a field. In my case, the ability to contribute to the shaping of a field is more subtle and refers to the ability to ask relevant questions and contribute to discussions. It relates to the notion of interactional expertise, which is the ability to master the language of a specialist domain while not having practical competence in the field (Collins & Evans, 2002).

Nevertheless, throughout this research I have engaged actively with the research subjects, asking questions that might have had a small influence in the way knowledge is produced in each field. In addition, the interpretation of the data can be influenced by one's own perceptions, views and biases. For example, my engagement with the Graphene Stakeholders Association brought me close to the operations of this association, to the point that I was asked to actively cooperate with their activities – an offer that I had to refuse. These two considerations are familiar to those who engage in participant observation and other ethnographic approaches, and require an active reflection on the position as a researcher and the interpretation of data. In this respect, I had to be "mindful" and highly aware of my bias, noticing that while my influence was not relevant to the point of shaping important aspects of the field, it did generate some surprise (what does an STS researcher do here? Why is she even interested in us?) and reflection for those actors I interacted with more immediately.

In the following, I explain the role of each of these data sources. The selection of sources was initially guided by general considerations (most cited articles, experts available in the vicinity) and later by the references made by actors and in other sources.

3.2.1. Document analysis

Emergent fields are in a state of constant and rapid change. Emergent paths and patterns show signs of stabilization. At the same time, these fields are in expansion, so while a technology might have emerged as a scientific discovery in a specific area of academic research, over time its promises and expectations move to other domains such as financial actors, policy makers, general media, etc. With the evolution of the field, the involved practices change. Therefore, to capture this shift in attention I traced expectations of each field in a heterogeneous set of documents (for a list, see Annex D).

Any intervention in an emergent field starts with a characterization of its ongoing dynamics and general trends (Parandian, 2012). To make a first characterization of each field I analyzed a set of most cited scientific papers, media reports and the work of consultants (marker reports and others). The two cases represented slightly different approaches in terms of the types of documents; this is because, as explained earlier, the types of actors and spaces are different.

For the case of graphene, I started with a characterization of the most cited research papers (including the work of Geim & Novoselov), paying particular attention to the editorial and news articles on graphene that were published by Nature. One of the relevant spaces in graphene, as I show in Chapter 4, is high-profile scientific publishing. Second, I extensively analyzed published documents related to the flagship application[47], starting from 2010 and until 2014, which included presentations, application and roadmap documents, among others. This was complemented by an analysis of media articles that were mentioned in the interviews. Last, a series of market and consultancy reports were analyzed to account for market expectations and practices.

For the case of 3D printing, a first analysis included an extensive review of previous research in STS and media studies about the technology, which is increasingly a topic of research in these areas. These types of documents mostly focused on maker communities, FabLabs, and the development of the consumer 3D printer. To complement it, I analyzed published reports from public and private organizations about the current status of the Additive Manufacturing Industry. After a first round of analysis, I complemented this material with specialized media discussions about 3D printing and consultancy reports, and reports/press releases by 3D printing companies. Additionally, specific policy documents from the European Commission were included.

3.2.2. Digital Media - Online Ethnography

Increasingly the use of digital media has become a common place for technology actors. From the use of blogs to specialized media and social networking sites, various tools enable the early circulation of expectations about a technology through the digital domain. There is an emergent area of research interested in the relation between social media and public framings of emergent technologies, which has studied how expectations about new tech-

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47 These documents are in most publicly available via the FET Flagship website and other associated EC websites.

nologies are spread and shaped in digital platforms (A. Anderson, Brossard, & Scheufele, 2010; Cacciatore, Scheufele, & Corley, 2011; Liang, Anderson, Scheufele, Brossard, & Xenos, 2012; Runge et al., 2013)

The diversity and pervasiveness of digital media today cannot be ignored, thus making this type of media a relevant tool and area of study for ethnographic research. In fact, considerable attention has been devoted to understanding the culture of digital media and how it influences, creates and supports certain social groups and social practices (Coleman, 2010). However, in order to understand how communities are constituted through online media, one has to look at their activities both online and offline, and how these mutually relate to each other (Boyd, 2013; Pelizza, 2010b).

Particularly helpful for my data collection was the use of certain social networking sites, such as Twitter and LinkedIn. I used these sites to contact informants, get to know about relevant topics and most importantly to make myself visible to the community I was interested in. Such online visibility allowed me to take part in discussions between "insiders" that are not accessible through general media.

A first observation was that there is an increasing use of social media for both graphene and 3D printing actors, although this might be for different reasons in each case. As it has become a trend in some scientific domains, graphene researchers use blogs and other media to promote their results other than scientific papers, which gives them visibility among their peers (Piwowar, 2013). Similarly, companies use these media to offer their services, because as they say, most of their potential clients – postdocs and Ph.D. students – are online most of the time (Arora, 2013 interview 8, graphene company CEO, December 2013). The case of 3D printing is the most obvious, since the origins of the consumer 3D printer are within online communities, which used forums and blogs to develop knowledge, machines and social relations (Söderberg, 2014).

For this reason I conducted an extensive analysis of relevant online content. This was comprised of two types: social networking sites (Twitter, LinkedIn and forums) and websites of relevant actors (consultancies, companies, experts, etc.). As in the previous case, there are differences in the relevance of each source for graphene and 3D printing. To select relevant accounts, my two criteria were: actors I knew from other sources (scientists, company owners, etc.) who were active in social media; and, popular and active accounts (accounts that showed activity at least once a week). I excluded from my selection media accounts dedicated to spreading and popularizing news. I instead focused on consultancies, scientists, companies, industry associations and technology bloggers. My initial selection of accounts expanded through the time of my research as I interacted online or in person with their owners. It is important to note that the selection of social media accounts does not intend to represent the whole universe of users related to graphene or 3D printing, but a representative group of actors who actively interacted through this media.

Social media I followed activities of relevant actors on Twitter (for a list, see Annex B). Twitter is a social networking platform in which users can post short messages (<140 characters), links, images and video. Detailed analysis of Twitter data has been used to map social networks, emergent trends, and others (Chew & Eysenbach, 2010; Conover, Gonçalves, Ratkiewicz, Flammini, & Menczer, 2011; Mathioudakis & Koudas, 2010). In my case, I used the platform to learn about ongoing discussions, find links to relevant documents and contact relevant actors. To do so I had my own Twitter account (@mariadelcuy) in which I added (i.e. "follow") relevant actors from graphene and 3D printing. To become visible for these actors I regularly posted news, or reposted ("retweet") information of other actors. In this way I created a specific profile which showed interest and some expertise in the field. Via these media, I became connected to several people (through their "accounts"), some of which later turned into interview partners or whom I met in person.

Twitter has a specific dynamic in terms of how messages spread. Expectations about the technology are circulated and commented on, often related to a news piece. Some of these "tweets" can contain references to other users by adding their account name to the tweet (to get their attention), get retweeted, 'favorited' and become popular (they will become top hits in searches, for example). This is facilitated by the use of hashtags (#3dprinting #opensource #graphene) that will index a tweet under these topics, and make it visible in searches (9). Twitter also enables users to send direct messages (DM) which are private messages. These were particularly useful to contact people for interviews, or to ask for specific information.

A second social networking site that I used was LinkedIn. In this case, the site was only relevant for graphene actors and not so much for 3D printing. This site was used differently: while for companies it was a way to learn about contacts and job openings, for intermediary organizations such as consultancies and industry associations, it was a sort of forum to have specific discussions (10). Another difference is that on this site it is necessary – not mandatory, but it is the usual practice – to use your real name and occupation, in contrast to Twitter and other forums where you can use a nickname. LinkedIn was used mostly by graphene companies and consultants to contact other innovation actors and to spread certain topics or get feedback on market related issues. I followed in particular the discussions of two industry associations: the Graphene Stakeholder's Association and The Graphene Council. These two organizations were founded during 2013 to bring together a range of innovators and speed up the development of graphene. Issues that were discussed in this platform ranged from scientific and technological news, to patents, market reports, and issues of standardization.

Lastly, I followed some relevant discussions in forums for 3D printing, such as the RepRap forum, subreddit 3D printing (https://www.reddit.com/r/3Dprinting/) and specific

Figure 9: This is how they tweet. The tweet includes references to the account of a company @Ultimaker, hashtags to indicate and index the topic which the conversation refers to, a link to the news item and a photo. It was retweeted 16 times (by myself included, green double arrows) and Favorited 17 times, this includes another company that I follow @YouMagine

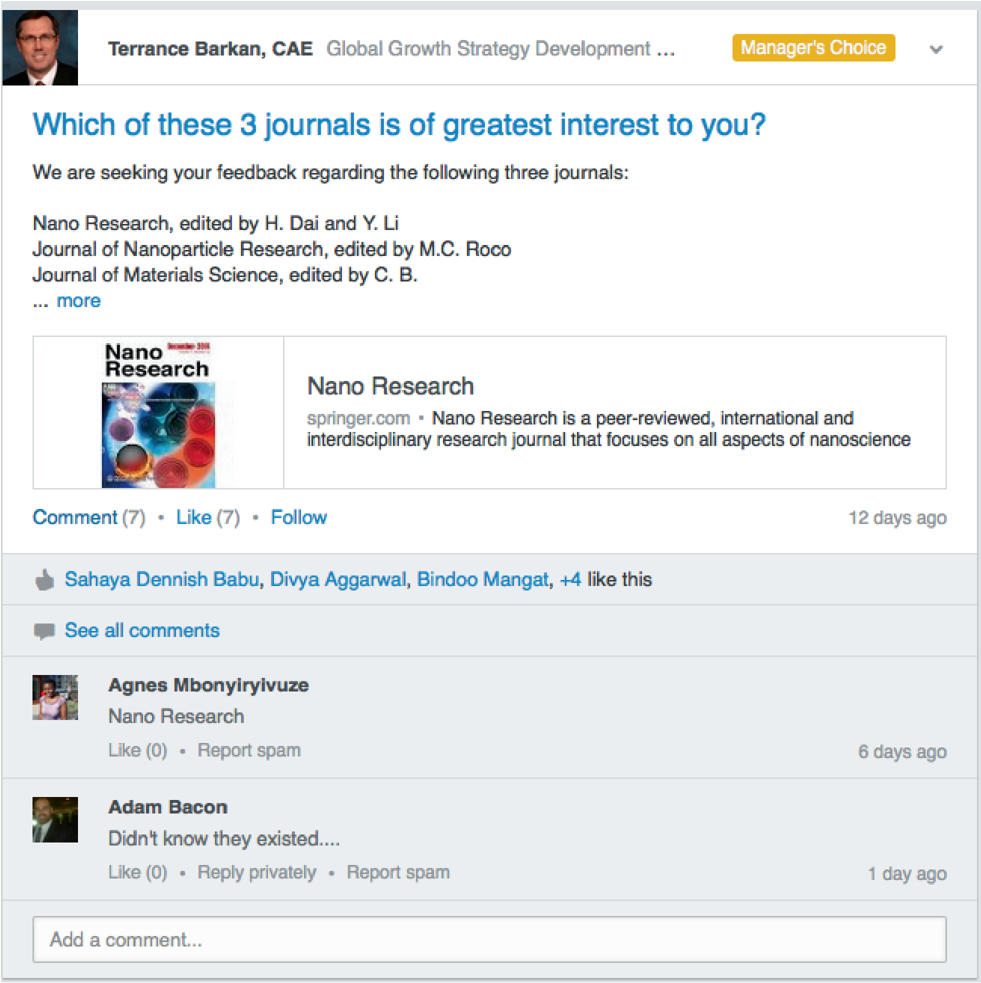

Figure 10: A conversation in the LinkedIn Group of The Graphene Council. To become a member of this group one needs to receive an invitation and be accepted by the managers. To do so, it is necessary to either show relevant expertise in the field through your CV or links with other relevant actors in the social network. Source: https://www.linkedin.com/grp/post/5153830-6032898126900195328?trk=groups-post-b-title

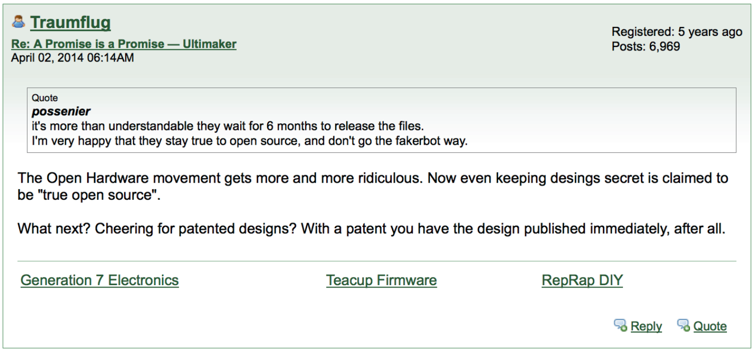

Figure 11: The RepRap forum is a large forum dedicated to discussions about 3D printing, ranging from technical issues to legal and regulatory, to the ethics and vision of the community in related topics. In this particular case, the user Traumflug responds to a thread that discusses the release of the source files of the Ultimaker2. He responds publicly to a comment by another user (possenier) by quoting his reply. Source http://forums.reprap.org/read.php?1,332823,333774

forums of consumer 3D printing companies.[48] Because the amount of information that can be found in these forums is very large, and because I was interested in an in-depth and qualitative analysis of the discussions, I limited my search to those discussions that referred to either the actors I was studying (Ultimaker, 3D Hubs, PrintR, DigiConnect) or topics that were relevant (what constitutes an open source 3D printer, etc., as in the case shown by 11). One interesting aspect of these forums is that often it is possible to directly "speak" to relevant actors. For example, the CEO of Ultimaker or 3D Hubs will respond to the questions of his users.

Websites, blogs and video In addition to these sources, there is a large number of videos available online (YouTube) about presentations by experts in the field who have taken place either in the context of meetings, conferences or workshops. In fact, it seems that it has become a common practice to upload substantial parts of conferences, workshops and trade shows to YouTube or Vimeo. In this case, particular actors or arguments become more visible. There are hundreds of videos related to graphene and 3D printing; among these, my criteria for selection were (1) videos that introduced the technology to a wider audience (e.g. those that would appear first in search); (2) videos that were referred to by actors during the interviews because they were considered to have had an important impact in

[48] Each company often has a forum enabled for discussions, which includes general questions, technical issues, etc. Many times these forums are in multiple languages.

the field; and (3) videos in which some interviewee – or a potential one – was participating. Such is the case of a Samsung concept video about a flexible touch screen enabled by graphene which was even quoted by the DailyMail and which had a strong impact on the expectations about graphene. [49] Thus, the type of video material that is quoted in this dissertation to support the accounts of practices that I describe is heterogeneous.

In addition, I analyzed the websites of projects (Graphene Flagship), consultants (IDTechEx, LuxResearch, Gartner, etc.) and independent consultants (The Econolyst, Voxelfab, GrapheneTracker, etc.). I approached these websites as texts, considering the way in which they presented expectations about the technology and the role of particular actors. The most interesting part of these websites was often a "blog" where news items were discussed. More than just news, the blog offers critical reflections about current developments in a field. Sometimes it would include interviews or videos, but often it would reflect on ongoing issues and make speculations about future developments.

Last, many of the conferences that are organized in these emergent fields are available via live streaming and/or later video. Similarly, consultancies often offer "webinars", which are like seminars but online, and in which the attendants can ask questions and see a "live" presentation of the analysts. Some of the accounts that are described in the empirical chapters come from the analysis of these videos. It is also interesting in its own right that this type of medium has become so important to spreading information and views about a technology. In fact, these videos are referred to, commented on and criticized in social media and news sites, and in this way they get more views.

3.2.3. Interviews

In order to learn about anticipatory practices by first-hand accounts of the actors involved in these practices, I conducted semi-structured interviews with a diverse set of innovation actors in graphene and 3D printing (for a sample of the interview's questions see Annex E).

The method to select interviews was based also on this recursive mapping of the field. I started with a list of potential interviewees, which was based on my initial assumptions, and which was extended and changed in the light of new findings. The interviewees were contacted via email or social media, but often they were contacted in events. In fact, this last method was the most successful to arrange interviews, with email being the least effective (low response). In each case, the interviewee was informed about the context and purpose of research and agreed with the anonymous quotation of some parts of the interview.

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49 http://www.dailymail.co.uk/sciencetech/article-2070741/Samsungs-transparent-flexible-screen-3D-real-looks-like-touch-it.html

I developed a guiding and general set of questions for the interviews related to promises and expectations about graphene/3D printing, and how these actors acted in relation to expectations (anticipatory practices). Each interview was tailored to the role of the interviewee (academic, consultant, CEO). Interviews were designed to elicit accounts of practices in which these actors were involved, as a means to understand why and how these practices took place and how they relate to expectations.

For the case of Graphene I conducted 29 interviews, either via Skype, phone or live: 9 graphene researchers, 4 consultants, 6 company CEO's, 3 flagship coordinators, 1 standards organization, 2 policy actors (NL and EC), 2 website owners, and 2 journal editors. It is important to note that those who are labeled as flagship coordinators are also researchers, but were interviewed in their flagship role. Similarly, some of the consultants belonged to consultancy organizations, while others were independent consultants. For 3D printing I conducted 18 interviews: 5 researchers, 2 policy makers, 3 company CEOs and company community managers, 3 consultants, 3 FabLab & makerspace members and 1 IP and regulation expert. It is important to clarify some of these distinctions. Some consultants were also members of FabLab or makerspaces, or worked – independently – with specific companies. For a detailed description see Annex A. All interviews were transcribed manually.

3.2.4. Technology Events

The last method of data collection was to participate in several "events" in which these technologies were configured. Such events, which can be considered as field configuring events, are relevant for ethnographic research since they are very fertile for the collection of data; they give rise to critical turning points of the social phenomena being studied; and they provide opportunities for interaction between innovation actors and researchers (Lampel & Meyer, 2008). At these events, one can observe the patterns and indications of emergent entanglements and dynamics of expectations (Parandian, 2012).

I attended in total 6 of these events, which included scientific conferences, trade shows, workshops and meetings (for a list of events, see Annex C). The purpose of my participation in these meetings was twofold. In the first place, these events allowed me to observe and take part in anticipatory practices (such as the discussion of a potential GSA roadmap and the presentation of the graphene roadmap to the scientific community, among the most relevant ones) and to observe the mobilization of different material forms of expectations (roadmaps, reports, prototypes) and the types of discussions these led to, making explicit the variations of practices that occur among different actor groups and the conflicts that arise from them. The second objective was to network and become a familiar subject in each of these fields. Realistically, this can only be achieved after an extended time of research; however, such physical interaction enabled some moments of close and informal interaction with innovation actors that provided interesting insights into the field. It also enabled me to expand my range of interviews.

For each of these events, I kept an ethnography diary with notes, pictures, videos and recordings, which were coded and analyzed together with the rest of the material. In some of these events I conducted informal interviews.

3.2.5. Data Analysis

I have used a heterogeneous and diverse set of sources and methods to reconstruct and understand anticipatory practices and their effects. In this last section I explain how I analyzed data to empirically identify anticipatory practices, and how I reconstructed some of their main characteristics and effects. This analysis can be characterized as grounded theory, in which I developed an appropriate framework for anticipatory practices based on my empirical material and through a constant revision of the framework based on empirical findings.

First, it is necessary to clarify how I empirically define something as a practice. I consider "practice" to be a set of elements (material, meaning, competences) that are brought together in a specific, characteristic and recurrent way and which has some common effects. This means that a practice can be identified by references to something actors "do", which has a characteristic structure that they recognize and speak about. In the case of anticipatory practices, the practice has a strong future orientation and/or contributes to shaping or spreading expectations.

These anticipatory practices can take two forms: explicit and implicit. *Explicit* practices are the easiest to identify, because innovation actors acknowledge them as future-oriented practices. For example, a roadmap is often referred to as a practice and a device that is used with the purpose of identifying future paths and opportunities for a technology. Similar is the case of scenario work, or vision-making, etc. On the other hand, *implicit* anticipatory practices are less evident. These are common techno-scientific practices that shape and circulate expectations, and through which actors in a field anticipate the future of a technology. Often, implicit and explicit anticipatory practices are interrelated.

To identify these implicit practices I focused on (1) the activities that innovation actors use to push a certain vision or expectation forward; and (2) the activities that they identified as useful to create a path into the future of a technology. These activities can essentially be discursive, referring to promises or concerns; or can be a way in which these expectations are spread, shared and shaped through the creation and circulation of material developments, such as prototypes, reports, etc. For example, in the case of graphene, high-profile publications were used strategically to position research in this area through the spread of expectations about its scientific and technological potential. Similarly, actors in 3D printing develop open hardware licenses to promote models of sharing of the technology, which they see as a necessary step to pave the road into a future for open innovation. I will use this last example to show how I draw on different kinds of materials to characterize these practices.

For a systematic analysis of practices, I coded all transcribed interviews, ethnographic accounts of participant observations and important documents (papers, roadmaps, reports, etc.) using the software for qualitative analysis Atlas.ti, in search of patterns that could indicate the existence of anticipatory practices. I conducted two rounds of coding, first searching for general references to action or activities conducted in relation to expectations and the shaping of the field. The second analysis narrowed down the type of practices identified to the most relevant and more clearly described in the data sources (such as roadmap, high-profile publications, patent application, development of legal standards, etc.), and to the relation of practices and other expectation-related categories (such as references to hype and intermediary organizations). From these codes I developed an outline of practices and their relation to the dynamics of expectations and the field. To complement this preliminary account, I searched in specific documents, web pages, or ethnographic accounts for references to the practices identified, creating a more comprehensive analysis of each practice as it took place in a specific context.

In most cases these practices became explicit in interviews, which became the most relevant source for references about practices. For example, when speaking to an innovation actor in 3D printing, he referred to the vision of his company in regards to open innovation, and how they considered this is as a central element of the socio-technical embedding of the technology. I deepened this aspect by asking what kind of things his company did to push this vision forward and why. He explained how the current legal framework for the development of hardware was limiting the possibilities of collaboration. According to him, collaboration is the killer app of 3D printing, and for this reason a legal framework that safeguards collaboration is essential for the spread of the technology. After this account, I searched and analyzed the documents of the licenses he referred to. Following this, I analyzed forum discussions about the development of these licenses, paying attention to how other users related this practice to the future of 3D printing. I conducted this analysis in a determined time period, so I could reconstruct the effects of the practice and how the practice changed over time and in relation to the innovation field. In this way, I reconstructed the meaning of the practice for a set of actors, and its relation to the future, and how actors engaged in the practice itself.

This example shows how I drew from different sources and actors' perspectives to analyze anticipatory practices. A similar approach was taken to analyze other anticipatory practices. While this type of reconstruction does not allow me to reconstruct practices in detail, it is sufficient to understand the position and role of different anticipatory practices in an innovation process, and the relations between them.

4. "We should take graphene for granted": anticipatory practices in emergent nanotechnologies (*)

(*) A version of this chapter is under review in the journal "Science as Culture"

Abstract. Graphene is a carbon-based material that promises to enable a new wave of disruptive technological innovation. As with other techno-scientific fields, graphene has been populated with far reaching promises and expectations, leading to over-promising and hype. This dynamic is the result of "expectation work," anticipatory practices that go beyond only rhetorical activities. From the circulation of promises in high-profile journals to calculative practices that shape emergent markets, the production of expectations in graphene is embedded in specific socio-material contexts. We follow the practices and actors that constitute the graphene field through its promises, by showing how interconnections emerge between spaces related to scientific, policy, or market actors. It is through the circulation of expectations, mediated by specific practices, that the boundaries between these spaces are blurred and graphene is constituted – and structured – as a field. This effect, which we refer to as performativity, corresponds to the articulation and co-production between the graphene field and the narratives about its future. The resulting dynamics, leading to overpromising and hype, can be understood as an assemblage of practices that connect across different spaces. In this respect, the observed dynamics of "hype" are more than the temporal evolution of expectations: they are the spatial structuration and transformation of a technology field and its future.

Keywords. sociology of expectations, graphene, assemblages, anticipatory practices, hype.

4.1. Introduction

On January 28th, 2013 the European Commission announced two large-scale research projects, each an initiative of 1 billion euros, with the Graphene Flagship being one of them. Organized around the promise and possibilities of graphene, a carbon material with exceptional properties, this project - presented as 'the EU's biggest research initiative ever'- is aimed at taking 'graphene from the realm of academic laboratories into European society' within 10 years, with high prospects for economic growth and innovation (GrapheneFlagship, 2014). This outstanding project is only one of the many initiatives that have been taken in the name of the promises of graphene. By highlighting its unique and impressive properties, actors in the field have triggered a wave of strong scientific, policy and commercial enthusiasm.

This collective enthusiasm for graphene has been translated into numerous scientific and mass media publications, research programs, start-up companies, patents, investments, and many others initiatives connected to and influenced by its promises. The circulation of expectations about graphene has increased considerably, to the point that there is a perceived (over)enthusiasm, leading to what has been called a hype. Enthusiasm for new science and technology is not a new thing. Rather, collective enthusiasm in the form of expectations is a constituent and intrinsic part of current research and innovation. These expectations play a central role in shaping emerging fields, and thus they are said to be performative. This has been observed with many new techno-scientific fields that have gone through phases of collective enthusiasm, often followed by some degree of disappointment, a dynamic labelled as the hype-cycle (Brown, 2003; Fenn & Time, 2007). It has been shown that these expectations, inclusive of hype, are performative by playing an important role in the mobilization, coordination and guidance of science and technology actors (Borup et al., 2006; Konrad et al., 2012; van Lente, 1993), and in the formation of these fields (Felt & Nowotny, 1992; Hedgecoe, 2003; van Lente & Rip, 1998).

In this article, we follow the rising enthusiasm for graphene and the role of expectations in the emergence of the graphene field through different spaces from academic science to commercialization. In particular, we introduce a practice perspective into the study of expectations in science and technology, investigating the different practices by which these expectations are produced. We focus on the (sets of) practices which shape expectations, enable their circulation within and across different actor groups and spaces, and produce particular performative effects. Furthermore, we aim to show how these practices connect across diverse spaces and support the constitution of a research field.

To fulfill these aims, we focus on two main research questions. The first one relates to the practices of producing expectations: *Which practices are deployed for creating, shaping and circulating expectations about graphene in particular spaces?* The second one refers to the relation between expectations and innovation: *How have these practices shaped the graphene field, i.e., what is their performative effect and how does this effect modify existing spaces?* By addressing these questions we aim to contribute to our understanding of the process of constitution of the emergent graphene field, and secondly, contribute to the discussion on expectations in science and technology by focusing on the relation between practices and their performativity.

This type of analysis will help us to gain a better understanding of the phenomenon of hypes in emerging technologies. These hypes or episodes of over promising are observed for a number of new technologies (van Lente et al., 2013). Hype can be understood as a strategic act of exaggeration by innovation actors (Ramiller, 2006) or as an emergent and collective phenomenon that is almost unavoidable (Brown, 2003). A hype is the result of the interplay between strategic voicing of expectations, unintended collective effects, and attempts to implement some form of expectation management in response to a hype (Bakker & Budde, 2012; Konrad et al., 2012). However, not enough attention has been given to understanding the conditions that explain the emergence and dynamics of hypes. Here we are interested in this phenomenon as the collective outcome of diverse practices. In this context, a hype performs a function for emerging technological fields: it brings actors together in early stages of technology development to take high risk decisions under high uncertainty (Gisler & Sornette, 2010; van Lente et al., 2013).

This article develops as follows. The first section introduces the main analytical concepts, such as the notions of *anticipatory practices*, *spaces* and *assemblages*. The second, empirical section is divided into four subsections, which describe four different *spaces*, and analyzes how particular sets of practices have shaped certain aspects of the graphene field, such as the sort of actors involved, the forms of interaction and coordination between them, and the directions research and development takes. These four spaces are high-profile science, public funding, emergent markets and risk management. The final section discusses these findings under the lens of the proposed framework.

4.2. Framework: Shaping Techno-Scientific Futures

The future as a central reference point for the way in which we conceptualize our world has long historical roots. The particular ways how projections are built and inform governance processes are specific for times and places (Jasanoff & Kim, 2009; Koselleck, 2004). In current S&T dynamics we observe a multitude of specific forms of anticipating and assessing the future, as well as future-agents & agencies, and intermediary organizations specialized in managing techno-futures. Furthermore, for current liberal democracies, anticipatory action plays an important role in coping with possible threatening events, just as in responding to the promises and risks of new and emerging technologies, such as nanotechnology. In this context, Anderson (Anderson, 2007, 2010) has suggested to pay close attention to the particular ways and practices in which anticipatory knowledge is built and how it leads to anticipatory action. In the following, we will explain our conceptual approach, which is aimed at capturing the diversity of anticipatory practices, their relations, interactions, and specific performative effects.

4.2.1. Anticipatory Practices & Performativity

The Sociology of Expectations has extensively studied the role of expectations in shaping technological fields. In cases where uncertainties and indeterminacy are high, expectations fulfill functions of mobilization, legitimation, guidance and coordination, in the absence of robust knowledge (Borup et al., 2006; van Lente, Rip, Disco, & Van der Meulen, 1998). Expectations, as 'utterances, inscribed in texts or materials, that circulate' (van Lente, 2012) are 'real time representations of future technological situations and capabilities' (Borup et al., 2006), which are assigned a certain likelihood. Expectations can take the form of promises or concerns; and it is particularly common for nanotechnologies to find promises accompanied by concerns; however their relation varies among technology domains (te Kulve et al., 2013). Expectations are performative; these statements are not just claims, but they have an effect on activities in the real world (van Lente, 1993). The concept of performativity refers to a recursive, evolving social process by which actors, technologies and even institutions in the real world adapt and align to the performative utterance (Michel Callon, 2007). We propose to study how this performativity is achieved by focusing on the practices by which expectations of the future are created, either explicitly such as in the case of calculations, scenarios, forecasting, etc.; or implicitly as in the case of the expectations embedded and embodied in grant proposals or prototypes (Anderson, 2010; Kinsley, 2012; Reichmann, 2013).[50]

For this purpose, we follow a notion of practices which define them as iterative and recognizable entities composed by a set of elements that are brought together every time the practice takes place (Shove et al., 2012). For example, roadmapping is a practice that varies considerably every time it is exercised but can still be recognized as such. We call practices *anticipatory* if they contribute to defining specific aspects of the future, either explicitly or implicitly (Anderson, 2010). It is important to note that while we pay attention to anticipatory practices, our aim is not to follow their occurrence in full detail, but to capture their main characteristics, and how they come together, more or less coherently as sets of practices that are relevant to certain actor groups and the linkages they create.

4.2.2. Assemblages of Anticipatory Practices

Following Callon's understanding of performativity, we suggest that these practices, as they come together, gain specific effects which are not achieved by each of them individually. Callon (2007) in his study on the performativity of economics in markets, introduces the notion of socio-technical agencements, or assemblages, to account for the set of heterogeneous elements that are brought together in the constitution of socio-technical systems such as markets. In a similar vein, the specific performative effects of expectations and anticipatory practices are co-produced by sets of practices which in their combination shape expectations. Thus, we conceptualize the particular configuration of practices as an assemblage – a situated configuration of diverse elements which has some consistency and regularity, and which co-produces the system it is embedded in (Collier & Ong, 2005).

50 We have explored these material practices in detail elsewhere (Alvial Palavicino & Konrad, in press).

This assemblage, that is constituted in relation to future expectations about a technology, exists within and across various *spaces*, which are social formations that pre-exist or emerge around a particular technology, and are characterized by a certain internal structure (Bonneuil, Joly, & Marris, 2008; Rip & Joly, 2012). The notion of space stresses that particular practices are deployed and enacted, contributing to the structuration of fields, through the arrangement of a network of heterogeneous actors and interests in hybrid settings (Kearnes, 2013). In the formation of this network, its elements, including the practices that constitute this assemblage may be added, removed and translated across different spaces (Collier & Ong, 2005). This means that these elements may belong to different spaces, and that the assemblage might change over time. Furthermore, different practices reinforce each other and connect with broader discourses about the future, which creates connections across spaces, blur their boundaries and makes the assemblage more coherent.

In sum, there are three elements to our framework. We take as the basis of our analysis particular sets of *anticipatory practices* and their performative effects. These practices constitute an *assemblage*, which shapes expectations and mobilizes particular actors and interests. This assemblage takes its shape and evolves in various *spaces*, which are interconnected.

4.3. Methodology

Our research is based on an in-depth case study in the development of expectations and underlying anticipatory practices in the graphene field carried out over a period of 18 months (end of 2012 to first half of 2014). In order to capture expectations and their associated practices, a recursive, mixed method approach was used. We characterize the method as recursive because the research scope was expanded in the light of new findings. The guiding principle was to map out relevant actors, their expectations and anticipatory practices, and subsequently, identify further relevant actors, expectations and practices. Based on a literature review, we started by interviewing scientific actors and following them in their relevant arenas of interaction. This included conferences, the Flagship project, intermediary organizations and social media.

In total, 29 semi structured interviews with graphene actors (EU & US) were conducted following a snowball sampling, covering: graphene scientists [9], science journalists [2], flagship coordinators [3], policy actors [2], consultants [3], venture capitalists [2], graphene company CEOs [6] website managers [2], and standards organization [1]. Interviews ranged from 40 minutes to one hour. One of us attended three graphene conferences (two scientific conferences and one business meeting). This was complemented with an extensive document analysis (scientific publications, press releases, interviews & videos, roadmaps, flagship documents), selected on the basis of themes raised in the interviews and in relevant social media.

The recursive, mixed method approach enabled us to trace a broad variety of interrelated practices and expectations. Still, the graphene field is wider than what is represented by our empirical material and analysis and our geographical scope is limited to Europe and the US.

The presentation of the argument is based on distinctive sets of practices which are rooted in particular spaces. While these spaces and sets of practices are characteristic for certain actor groups and develop in a temporal sequence, it is important to note that the distinction between them is guided by analytical concerns. Actors may participate in different practices and spaces. Furthermore, as will be seen, each of these sets of practices contributes to the constitution of the other, and there is temporal overlap between them.

4.4. The promises of Graphene

This section analyzes the development and evolution of the graphene field through three spaces of the anticipatory assemblage of graphene. Each of these spaces relates to specific sets of anticipatory practices, characteristic of relevant actor groups that have shaped graphene. The first space shows the interplay between science actors and the scientific publishing system in the constitution of graphene as a technology field. The second space refers to large-scale public funding mechanisms and the specific practices attached to them, articulating expectations of graphene in relation to its economic and societal implications. In the third space it is discussed how intermediary organizations and other market actors develop and shape the emergent graphene market. Expectations related to graphene have evolved through these three spaces, as it has moved from a scientific field into a technology in the process of commercialization.

4.4.1. The "High Profile Science" Space

When Andre Geim decided to put his recently arrived Chinese PhD student[51] to isolate graphene from graphite he was not expecting to win a Nobel Prize, although he was thinking big. Why don't we make a transistor out of graphite? he suggested to his collaborators (Whittel, 2014). But for these 'Friday night experiments'[52], things turned unexpectedly positive, and very interesting results were obtained by the end of 2013. Through mechanical exfoliation (or the scotch tape method) Geim's lab was able to isolate graphene of few layers and observe some of its unique electronic properties. These were not just interesting

51 Da Jiang, his first PhD student at Manchester arrived in 2002. He currently works in a graphene spinoff. However, it was not Da Jiang's approach, but Oleg Shklyarevskii' approach that enabled the first isolation of graphene. (Geim, 2010).

52 Experiments unrelated with one's official source of funding done outside working hours. Geim's Friday night experiments include floating frogs that gave them the Ig Nobel Prize. The Ig Nobel Prize is a 'parody' of the Nobel prize, given to scientific discoveries that make people laugh first, and then think.

measurements, but promised to reconnect high-energy and condensed matter physics by enabling the study of quantum phenomena at room temperature (Interview 18, graphene researcher). The two Russian scientists knew they had something, so they aimed high - a *Nature* paper. The road proved to be trickier than expected, and the paper was finally out in 2004, though not in *Nature*, where it was rejected twice, but in *Science* in October 22, 2004 under the name 'Electric Field Effect in Atomically Thin Carbon Films' (Novoselov et al., 2004).

This short paragraph summarizes the foundational myth of graphene: two Russian scientists isolate, only with scotch-tape, an amazing material that revolutionizes physics, electronics, and potentially the world. While there are many nuances to the story (Dresselhaus & Araujo, 2010; Dresselhaus & Terrones, 2013), this is the myth which has partly fueled the hype on graphene. One important feature of this story is the relevance given to publishing in high-impact journals (or glossy magazines, as Geim has referred to in his Nobel lecture) such as *Nature* and *Science* (Palla, Tibély, Mones, Pollner, & Vicsek, 2015). These journals played an important role in shaping graphene already at its early stages and in supporting its development into a quickly expanding and high-promise techno-scientific field. Not only by publishing research results, but also by actively helping to articulate visions and communities of graphene.

While the breakthrough paper of 2004 did not make it into *Nature*, the long relationship between *Nature* and Geim & Novoselov started already with a publication in 2005. This paper appears in the format of a *Letter*, a type of article which is targeted at presenting outstanding findings supposed to be of interest to scientists in other fields. It introduces graphene to the scientific community as a bench-top model for quantum measurements, that is, it allowed to make quantum measurements at room temperature (Novoselov et al., 2005) . This particular property of graphene mobilized the interest of a large scientific community. After this, graphene related publications sustained and increased. To date, *Nature* has published about 50 papers authored by either of these authors[53], including four review articles. Additionally, it has published thousands of graphene-related papers, news, comments and two *Special Features*. Besides the number, it is the type and content of the publications and its influence in shaping particular expectations that is interesting.

One largely cited publication of graphene (13,000 +) is a review paper of 2007 titled 'The rise of graphene' (Geim & Novoselov, 2007). This paper announces: 'the graphene "gold rush" has begun' (pg.183). The publication looks into the future of graphene by acknowledging its past and the past of other relevant nano-materials. It makes explicit claims about its economic and innovation prospects, only two years after its isolation. This progress article follows the direction(s) of this emergent field. The authors tell us that '(…) only the very tip of the iceberg (in graphene research) has been uncovered so far' (pg.190); many

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53 By October 2014.

experimental groups still do not have relevant research and therefore no comprehensive review is possible to the date. The authors go on to state, however,

> (…) graphene is not a fleeting fashion but it is here to stay, bringing up both more exciting physics and perhaps, even wide-ranging applications (Geim & Novoselov, 2007, pg.190).

In fact, the paper appears as a nicely elaborated invitation to the broader scientific community to join the graphene "gold rush" by doing a fantastic articulation and expectations work. It defines the field by acknowledging its past and looking into the future, and with the authoritative figure of one of its founders. It does so by relying largely on the physics and referring rather casually to the promises of graphene, without deeper elaboration.

In addition to the research papers themselves, *Nature* has published a number of editorials, features and comments on graphene. With regard to one of these first commentaries entitled 'Moving towards a graphene world' (Van Noorden, 2006) and discussing graphene's potential in electronics and recent advances in producing graphene (Van Noorden, 2006), a *Nature* journalist explains:

> (…) Clearly this is an article commissioned because, the Nature editors, who are separated from journalists, have had to accepted this research paper. And (…) I don't know if you know but science journals will often keep press releases of papers that are going to come out on an embargo basis. So obviously we've seen that and we think this is an interesting material and try to make a news piece to a wider view about what graphene was. (And in reference to the aim of the paper, he adds) (…) people slightly outside of the field (…) can read that and realized that this is a field that they should be interested in, because they never read that original paper.(…) (Interview 24, science journalist, June 2013)

He explains how this particular form of publication, the *News feature* in *Nature*, is used to strategically spread expectations about new exciting science among an extended community of researchers. He also comments on the practice of attaching commissioned press releases to papers that are going to be published, which increases the attention to a broader audience. He furthermore points to the particular role of *Nature* in mediating between the scientific and public audience.

> Nature Publishing also owns Scientific American, so that is more public realm, but let me just say that many of the articles are taken up by The Guardian and so on, so this case of a mixed audience is interesting, often Nature articles get referred to in mass media articles, in the BBC or in the NYT. (Interview 24, science journalist, June 2013)

This editorial was indeed quoted and taken up in English-speaking news items[54]. So, particular publishing formats were used to open up the graphene field beyond the physics community, and helped to spread expectations about potential applications and set up the requirements to meet these expectations, namely, the issue of finding suitable production methods.

These publications contributed to connect explicitly the expectations about graphene with an overarching, prominent expectation: the end of *Moore's law*, the assumption common to the electronics world that the trajectory of decreasing size and increasing capacity of silicon-based computer chips may reach its physical limits soon. It was suggested that graphene could provide a solution as the basis of the next generation of transistors. Specifically, the reference to graphene in electronics is made in the progress article of 2007, 'The Rise of Graphene' which is cited already in the 2007 edition of the ITRS roadmap (ITRS, 2007), the roadmap that supports the continuation of Moore's law. In fact, the idea that a new nano material would provide new ways of dealing with the limits and limitations of Moore's law is not new (Choi & Mody, 2009; Spinardi, 2012) and it has played a central role in the development of nanotechnology as a field, particularly in the US (McCray 2005; 2009). In relation to this, a journal editor reflects,

> It is interesting that there seems to be almost a receptive environment (in the science media) for people to come and say this is a wonder material that is going to do all these great things in electronics. It's almost like we were prepared for that (…) because there has been a lot of talk over the past 10, 15 years of how silicon, microelectronics is reaching its limits. No one knows what's going to come next but everybody is expecting that something will come next because we gotta keep up with Moore's law, the computer companies have expectations that they want to meet now. And so the idea that graphene might solve all of these problems seems to be an attractive one and comes on time for that reason. (I.23, journal editor, July 2013)

This was a powerful initial expectation to relate to by this early assemblage, but it could not be easily achieved because of the absence of a band gap in graphene. Silicon, the standard material of transistors, works because it has an energy gap –a band gap- that enables it to switch between on and off states. Graphene has no band gap, thus it is not possible to modulate the electron current and cannot be used for digital electronics under these conditions. Nevertheless, this was not a reason to exclude this early promise, and many attempts have been made to develop a graphene transistor.[55] Furthermore, the

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54 Using the LexisNexis database.

55 The promise of graphene for electronics is, however, not fully given up, as reflected in a recent announcement (July 2013) of IBM to invest 3 billion dollars in 5 years in the development of CMOS technology for 7nm and beyond, as a means to continue Moores law. This approach includes carbon nanotubes and graphene. (http://www-03.ibm.com/press/us/en/pressrelease/44357.wss).

pervasiveness of the expectation opened up research to whole new kinds of 2D materials that could fulfill this promise instead of graphene.

We would like to argue that the role of high-impact journal publishing, here exemplified by the role of *Nature* in shaping the graphene field, goes beyond providing a mere platform for the circulation of expectations voiced by scientists. These high profile journal publications became a core element in the structuration and expansion of a network of researchers in graphene, represented by the articulation of specific expectations, and the mobilization of an extended community into the field. Researchers such as Geim and Novoselov strategically decide to publish their results through this medium, and furthermore, engage in expectation building activities with their support. This space is composed by various practices: scientific publishing of different formats, press releases, editorial choices, and others such as the distribution of these publications though mass media, social media, conferences, and other networks. Through these, the emergent graphene assemblage gains legitimacy when the expectations produced by these practices were interlinked and framed in relation to broader expectations – such as Moore's law. These practices are reinforced by an institutional context that gives high value to publications in high impact journals and that encourages the framing of scientific results in terms of its potential applications and value.

This early assemblage, constituted around a growing scientific community within a promissory techno-scientific field, soon moved further into the techno-economic promises of graphene. A group of European scientists applied for a large-scale funding scheme recently launched by the European Commission. This was the beginning of the Graphene Flagship, where scientific visions met policy expectations about the material, a process we will analyze in the next section.

4.4.2. The Public Funding Space

In October 2010, Andre Geim and Konstantin Novoselov received the Nobel Prize in Physics 'for groundbreaking experiments regarding the two-dimensional material graphene'.[56] This event marked the beginning of graphene in the public sphere. Shortly before the announcement of the Nobel Prize, a group of European scientists presented graphene as one of the early 26 candidates for the Future & Emerging Technologies (FET) flagship scheme. The scheme required a Europe-wide, bottom-up scientific project that would bring innovation, growth and address societal challenges. In the first presentation of the graphene proposal, in 2010, the project was framed as taking graphene 'from the Nanolab to reality' by addressing the issue of production (Kinaret, 2010). Other proposals were formulated more closely in the terminology of societal challenges (Interviews 23 and 12). Nevertheless, by 2011 the Graphene Flagship was among the last six finalist proposals.

56 http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/press.html

A scientific coordinator of the flagship explains the need to adapt expectations shaped in the science space to the frames of the policy space, and to the requirements of the funding scheme:

> We took the opportunity to apply to the flagship within a concept that was suggested by the European community. And immediately we thought, how do we make graphene broad and with broad societal impact because that was what the (EU) was looking for. They were looking to fund a project that had societal impact and so on and so forth. (later he adds) in order to be selected you have to comply with the requirements, and one of the requirements was this vision, we needed to have this vision. (Interview 3, scientist and flagship member, May 2013).

This scientist highlights how the flagship funding scheme is linked to a specific vision of technology development promoted by the European Commission: technologies that address societal challenges and economic growth.

Adapting expectations was not only a rhetorical move creating legitimacy and connectivity for the promises of graphene, but the funding scheme also required to deploy a specific anticipatory practice – the development of a roadmap (Boch, 2011). The specific form of the roadmap was left to the flagship applicants, and the process chosen proved to have a significant impact for the graphene community. The roadmap was created through a process of public consultation. There was an open online form that gathered numerous inputs, but also created many expectations on the project itself (Interview 16, flagship member, January 2013). In a conference, one of the roadmap coordinators said that during this open call period they received so many proposals and ideas, that it was hard to include them all. Therefore, the proposals to be considered in the eventual roadmap were selected by an expert group, which in this way did not only exclude ideas, but also research groups who had initially responded to the call. This created some skepticism among the scientific community and diminished, to some extent, the perceived trust in the process of setting up the flagship. The roadmap exercise did not only give shape and legitimize a common vision of the consortium, but also mobilized the whole European scientific graphene community, and served to decide who was in or out. As noted by Kearnes (2013), roadmaps perform the double function of crystalizing discourse about a field and of defining the network of actors that constitute this field.

The roadmap of the Graphene Flagship which eventually resulted from this process was considered the 'crown jewel' of the whole proposal by one of its coordinators, supposing to give direction to graphene research not only within the already large flagship program, but also to the graphene community worldwide.

> (…) before that there was no roadmap for graphene and now there is a clear direction for the next few years. (…) You know the semiconductors, there is the ITRS, so this

> would be the equivalent for graphene and related materials (...) we want to make it public, accessible for everybody, as the ITRS. It will be a very important document and as soon as it's out people will criticize so we will improve it, we will get more inputs from industry so we can improve the roadmap and get better results. The roadmap is key to achieve better results, it will give the direction to the future to the entire community, not only the community within the flagship but the entire community in the world (Interview 3, scientist and flagship member, May 2013)

This quote further highlights that in deciding for the particular roadmapping practice to be deployed, the coordinators were strongly inspired by another, firmly established and highly effective anticipatory practice: the ITRS, the roadmap of the semiconductors industry that supports the continuation of Moore's law. For many of the interviewees, particularly from the science domain, the ITRS is a model roadmap. Some researchers see the translation of the rules of this particular practice to the graphene field as rather unproblematic, and aim to make it even more similar to the ITRS in the future, while others reflect on the different context of the practice, mentioning that '*the difference is that the semiconductor industry is large, well established, a little more predictable because it exists basically, and it's large. In the case of graphene it is different*' (Interview 12, graphene scientist, June 2013). Still, this same researcher acknowledges the expected general coordination function of the roadmap when adding that doing this roadmap in itself is a 'good exercise' as it allows the writers of the roadmap to find 'consensus in objectives' and because it 'synchronizes the activities of all the groups, also those that don't write it but use it'.

This roadmap was translated into a publication in *Nature*, called 'A roadmap for graphene' (Novoselov et al., 2012), thus linking up with the practice of review papers well established in the science space, and which we consider an *anticipatory* practice as introduced in section 2. In relation to this publication, a *Nature* journalist explains that

> (...) they (journal editors) like reviews because they get more citations, these are more cited articles. But also it's a service to scientists, people want to know what's going on. Now in this particular case this roadmap was colored by the fact that graphene was in the bidding for 1 billion euros European funding, which did actually win, so at that time all the projects that were in the bidding were trying to write reports and reviews on the potential of the entire field. And I think that this review was tied to this type of interest of where are we now, and where are we going. (Interview 24, science journalist)

The roadmap publication spares no expectations, and, as the journalist alludes, it was strategically published to support the flagship selection process. It starts by asking if graphene could become the next disruptive technology, adding that the material has the potential to both replace existing materials and create radical changes. The document deals with a diverse number of applications and forms of production of graphene, talking about a hierarchy of applications and introducing requirements for graphene to be really disruptive in relation to existing industries (Novoselov et al., 2012). Graphene is portrayed as the next disruptive technology. This view is now common not only within science, but has spread into other contexts such as research policy (InnovationUnion, 2011; UniversityofManchester, 2012).

More recently, the full roadmap document (over 300 pages) was published in the journal *Nanoscale* (Ferrari et al., 2014). To date, there are three roadmap publications associated with the flagship: The roadmap submitted for the flagship application (Kinaret, 2012), the *Nature* publication, and the recent publication of the full roadmap. These multiple versions of the roadmap indicate the different functions this practice has had for the flagship. In the first two cases, the roadmap was part of the application process and was used to legitimize and create momentum in the field. The latter, complete roadmap publication is aimed at fulfilling an ITRS-like function: to guide and coordinate the graphene field and serve as a medium for discussion in relation to its development for the future.

In January 2013, the Graphene Flagship was selected as one of the two consortia to be funded by the European Commission FET program. Scientific excellence aside, there were additional developments that help to explain its success. The ongoing patent race on graphene, in which Europe was behind, was related to the *European Paradox* (Interview 7,10,16), a belief according to which Europe is able to do excellent research, but less capable to capitalize on the resulting innovations. Would this be the case for graphene? Early assessments of the patent landscape (IPO, 2013) showed that while Europe was the leader in publications, it lagged very far behind Asia and the US in terms of patents. The flagship was partly a response to this concern.

While the flagship was announced as a one billion euro project, the actual funding was a promise. It would have to be negotiated every year with the EC under changing conditions of financing (Peplow, 2013). The scheme was expected to mobilize enough attention so it would be able to deliver the promised amount of funding. A member of the FET program from the European Commission said:

> (...) if in the end the flagship becomes a big success we will not need all the EU funding, we managed to generate enough interest from other people putting money and our money becomes only a catalyst, so to speak, for the funding. (Interview 7, member European Commission, June 2013)

That is, the flagship does not only build on the promise of graphene, but it is explicitly supposed to further support this promise, which is also reflected in the funding rules. The FET Flagship funding scheme was the first of its kind, and therefore high expectations were placed on the scheme itself, as it is expected to prove the ability of the EC to boost innovation and coordinate a European–wide network of researchers for this purpose[57]. Graphene fit these requirements, because there was already a vibrant community of researchers and companies working on fulfilling its promises. As discussed in a *Nature* news feature, the project has already been successful in mobilizing additional funding by national governments and large industrial partners (Peplow, 2013), thus indicating that the approach to both build on and reinforce the promise of graphene so far seems to have worked out well. Rhetorically, Jari Kinaret, the director of the flagship, has even turned the promise into a fact by stating that instead of doubting the potential of graphene, 'we should take graphene for granted', as any other broadly used material (ibid: pg.327).

The anticipatory practices related to the application to the flagship funding scheme helped to coordinate the discourse of graphene with the discourse on societal challenges promoted by he European Commission. What is more, new actors and anticipatory practices joined this assemblage and became increasingly relevant, for example the ongoing patent race and its ability to connect with visions of economic growth. The roadmap helped to coordinate this wide range of actors and mobilize further interest, creating a hierarchy that is not only about applications of graphene, but also about which research groups will get funding at which time. The promises that were articulated earlier through high profile journals served as a basis to support its societal relevance and be funded by such a large scheme. As we have shown, the expectations about the societal and economic relevance of graphene were perpetuated in the funding scheme it was selected for, and Nature continued to play an active role in articulating expectations dynamics in the field.

4.4.3. The Emerging Technology Market Space

Let's now turn to an essential component of the anticipatory discourse on graphene: the market. As explained, one of the main objectives of the Graphene Flagship has been to contribute to economic growth. In these discussions there is implicitly a growing attention to the value given to graphene, or rather the graphene market.

Anticipating the graphene market includes the development of forms of commercializing graphene as a tradable product. This process led to new practices, actors and expectations linked to the graphene assemblage, particularly graphene related startups and other market actors. Many new graphene companies were created around 2010, at the same time the Nobel Prize was granted. While expectations are used strategically by all actors, market actors have a particular interest in using expectations as a means to attract venture capital and other funding in the early stages of a technology. Wüstenhagen et al. (2009) and Konrad et al.(2012) have shown that venture capitalists respond to expectation dynamics in their investment behavior and partly try to shape expectations

57 The Flagship scheme was also aimed at boosting the ERA-network (http://www.flagera.eu/graphene).

themselves. A CEO of a graphene company confirms the strong effect that the boost in graphene expectations by the Nobel Prize had on their firm.

> We started (the company) just a few months before the Nobel Prize. And after the Nobel Prize interest just jumped. Our sales jumped by factor of 5 in two months. (Interview 8,CEO graphene company, December 2013)

This graphene company, among many others, used the attention of graphene to position themselves in this emergent market by doing press releases, participating in conferences and being active in social media. In this way, these technology and market actors engaged actively in expectations work, publicizing their activities and linking up with ongoing discussions within the community.

One of the challenges at this early stage was to set a value for the graphene market. This is where a specific type of actor, so-called promissory organizations, entered the field (Pollock & Williams, 2010). From 2009 onwards, specialized consulting organizations attempted to give a value to this market. Among these companies there was *LuxResearch*, *IDTechEx*, *BCC* and *Cientifica*, all well known in the nano world (Bünger, 2008; Parandian et al., 2012). In their assessments they concluded that the enthusiasm was higher than the actual prospects of value for the graphene market. Supposedly, the graphene market would not grow considerably in the following years because there was no unique, killer application[58] enabled by graphene that could create a huge economic success in the short run (Cientifica, 2013; Kozarsky, 2013; LuxResearch, 2009). The overall assessment was that graphene was overhyped.

The company *IDTechEx* considered the graphene hype as a central dynamic to take into account when developing strategies in this emerging field. This idea was presented in conferences and spread across the whole community. To go against the hype, the main message was:

> *Graphene should be more than a 'I am cheaper than the other guy material'.* (Ghaffarzadeh, 2013)

More specifically, the quote implies that graphene is an early technology, there is no 'killer application' and it is not going to succeed by replacing existing materials. The quote also illustrates the type of knowledge that these organizations claim to have in relation to the graphene market, and how this knowledge is presented, which varies considerably from scientific knowledge as reflected by the language used. It is worth considering how such an organization is able to position its assessment of the future of graphene within the broader community and for what purposes. Consultancy organizations engage in various practices –

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58 Killer application refers to a technology that is so necessary or desirable, with distinctive advantages over existing technologies that becomes the main source of value for a new market.

they release reports, blogs, do conference presentations and one-to-one conversations with companies or relevant scientific actors. These practices are constantly enacting the position of consultancy services in the community, and thus also their expectations. However, these organizations make a living out of selling market reports, organizing events and seminars and offering specialized services to companies, so part of their business is to keep expectations high about themselves – and about graphene.

Another important aspect is the different ways in which these new graphene companies obtain funding, and how it shows the interrelation between certain practices and expectations across different spaces. The availability of venture capital for these companies has fluctuated considerably during the years. This situation changed when Chemical Vapor Deposition (CVD) was introduced as a production method for electronic grade, high quality graphene, particularly when the method proposed by Samsung was presented in a *Nature* paper (Bae et al., 2010). This indicates that at the time venture interest was fostered both by the Nobel Prize and the appearance of the new production method (Interview 8, CEO graphene company, December 2013). However, this interest dropped when the multinational chemical company Bayer stopped its activities in carbon materials in May 2013 (Biondi, 2013). Following the flagship announcement, interest was renewed, and some UK based companies went into Initial Public Offerings (IPO). To attract investors, these companies rely on their patents portfolios, which are not necessarily used by the company in the long run (Interview 8 and 27, graphene companies' CEO). Additionally, they also deploy market reports (Interview 27 CEO graphene company) and publications such as the graphene roadmap (as seen in conferences attended) to legitimize the expectations of this future graphene market.

The interest in graphene investment that preceded these events had been growing for some time. In addition to consultancy organizations, many graphene business related websites appeared (Graphene-info.com, graphenetracker.com, thegraphenecouncil.org, etc.). These websites are worth noticing because they do not operate as a traditional media source, or a consultancy organization. Instead, the managers of these websites have a strong belief in the promises of graphene and want to provide factual, 'non-hyped' information through the site, as illustrated by the following quote by a website manager:

> I wanted to write an independent page about that (graphene business) from my own, you know, experience (…) On the website I try to get rid of that (hype, overpromising) so not to promote it (…) I try to be real, I don't want to seduce people, no one is paying me to advertise their company in the investment page (Interview 10, graphene website manager, June 2013)

Thus functioning as a 'hub' for graphene and strongly connected through social media (most notably, LinkedIn), these websites become a site for reference and discussion, especially for companies. Members of graphene companies know the managers of the websites personally, and endow them with insider information and perspectives (Interview 28, website manager, December 2013). At the same time, these companies trust the managers of these websites and consider them 'independent experts' (Interviews 8, company CEO, and interview 9, venture capitalist, 2014). Content wise, these websites provide considerable information about the market dynamics of the field (patents, companies, merges) and by doing so, help to shape this market and its future developments.

While these are only snapshots of the process of commercialization of graphene, it gives us some insights into the type of expectation dynamics and the multitude of actors we find in this space. One salient aspect is that this space introduces anticipatory practices that enable the quantification and calculation of the future of graphene. These are performed by specialized future actors, consultancy organizations that gain their legitimacy through various practices that range from networking to calculative models. While the sheer numbers itself provided by these reports are not the most relevant aspect (assessments can vary considerably from one report to the other), it is the proposed type and path of the future that becomes a forceful element. Consultancy companies have to create a space for themselves in the expectations business. Therefore they engage in a double, ambiguous role: on the one hand engaging in practices of calculation and checking of expectations - making sense of the hype. On the other hand, they have to keep a certain level of expectation to ensure that this market space does not collapse completely.

New companies use the existing enthusiasm for graphene to obtain capital, either by venture or IPOs. However, the availability of venture capital fluctuates easily in relation to changes in the field, thus startup companies need to engage in *expectation work* in order to be able to keep up with funding opportunities while at the same time deliver in relation to these expectations, avoiding the hype-disappointment effect. These companies embed themselves into a network of expectations which is partly facilitated by specialized actors, websites and social media, where they find expertise and check their peer's performance in relation to future prospects.

4.4.4. The Risk Management Space

One of the characteristics of techno-scientific regimes is the need to control and regulate potential risks (Joly, 2010). As the attention to graphene grew, the need to anticipate potential risks and concerns became stronger. There was the expectation that big promises could be accompanied by societal concerns. This generalized expectation is a shared belief for many emerging technologies (Rip, 2006). As a graphene scientist explains, concerns are to be expected,

> I think there is going to be concerns (about graphene). Interestingly I saw an interview it was held with the person that is heading the graphene flagship where this questions was also raised, are they dangerous? He was actually interview by Nelly

> Kroes,[59] so he said no, it is carbon based so it is OK. I think that's very naïve. Maybe he said it for political reasons, not to awaken any concerns but I think the concerns should be there (Interview 17, graphene researcher, January 2013)

This researcher expresses how it is expected that concerns take place; in fact, he makes a normative statement about concerns needing to be there as a way to responsibly develop the field. In 2012, following this line of thought, such "concerns" started to be discussed among members of the graphene community. In particular, this discussion focused on Environmental and Health Safety (EHS) issues and the development of standards. The process of application to the Flagship was central to articulating this discussion. As is the usual practice for projects under the European Commission, the flagship was asked to address EHS issues of this new nanomaterial. One of the eleven work packages (WP2: Health and Environment) is dedicated to this topic. A coordinator from the flagship explains the organizational logic behind this WP.

> (The Work Package on Health and Environment) … is really a world class set of scientists, and it is extremely important for any new material that the implementation of the applications is done in an environmentally acceptable and safe way, so it has always been a pillar of our work (…). There was no question at any stages that this would not be there (Interview 3, flagship member, May 2013).

As he explains, accounting for the risks and societal impacts is a requirement for any project funded by the European Commission, a task which is often delegated to a specific scientific community (Laurent, 2013). The integration of risk research is a taken-for-granted component of any large research project, and scientists are well aware of this. In this particular arrangement, scientists other than risk researchers only bear the responsibility of taking precautionary measures when using the material in the lab (Interview 17, graphene researcher, January 2013). Along these lines, the same flagship coordinator argues that he is not worried about graphene, but that addressing risk issues is part of its responsible development.

> I don't think there is anything to worry about whatsoever (…). But, on the other hand, you need regulation, you need to tell the regulators that there is no problem (…). We didn't put the Health Work Package because we are worried, absolutely not. It is because it is necessary to act in a responsible manner and scientifically prove and develop regulations that make the material completely safe. (…) For this reason we have the work package, it is not because we are afraid of anything, it's because it is extremely important to act responsibly when you have a new material (Interview 3, flagship member, May 2013).

59 At the time of this interview, Nelly Kroes was the European Commissioner for Digital Agenda (until November of 2014). It is within this Directorate General that the FET Flagship projects were organized, hence the interview.

As explained in the quote, the WP on Health & Environment is the way the flagship responds to implicit societal demands of safety of nanomaterials. In this institutionalized form of addressing risks, resulting from previous experiences with carbon nanotubes and other materials (Rip & Van Amerom, 2010), is embodied a particular idea of a "responsible development" of graphene: sound science to assess risks that enable regulators to create a framework to operate safely. Concerns about graphene are translated into a clearly defined procedure, in which tasks, expertise and accountability are distributed. As repeated by many interviewees, it does not matter if you believe whether graphene could pose any health risks; regardless, risk assessment is part of the structure of research. In this way, uncertainties are erased from the discussion, and preventive measures are deployed (Anderson, 2007)

While concerns have not become a major issue, they were discussed within the broader community. In a business-oriented graphene meeting, the issue of risks was discussed in the context of past experiences with carbon nanotubes.[60] The meeting was organized by the GSA,[61] a graphene business association whose motto is to "enable the responsible development" of graphene. In this meeting, co-located with a larger nano business meeting, industrial actors also acknowledged the importance of risk research. However, this was again demarcated as a practice detached from the core operation of these companies, as explained in the following quote:

> I know that [EHS research] is important but on the other hand I don't see who is going to pay for R&D work associated with these kind of issues. So I think the government should step in, not small companies like ours, we are just surviving. We can sell products from R&D, right now we assume that everything that we sell will be operated by scientists that are qualified to operate machinery so it's basically, when we sell a product we give all the liability to the end *users* (Interview 8, CEO graphene company, December 2013).

In this quote, the CEO of this company detaches their activities from the responsibility of dealing with EHS issues. As long as the consumers of graphene-products are other researchers, then the responsibility to understand the risks is of those who buy it: the scientists. If it is the case that products become available for the general public, then it is the responsibility of the government, or other policy bodies, to provide the adequate regulation for handling graphene. In the end, the company seems not to be accountable for the management of risks.

60 Many of the members of these business associations have had a past experience with Carbon Nanotubes. In fact, graphene, in terms of its properties and the rhetoric associated with it, has a strong resemblance to previous carbon material hypes (Cientifica, 2013).

61 The Graphene Stakeholders Association (http://www.graphenestakeholders.org/).

As a result of this new research agenda on the risks of graphene, a number of publications addressing this issue appeared, starting in 2011.[62] These publications, which address the risks of different types of graphene, make explicit the need to provide accurate definitions for the different types of materials that the label "graphene" embodies. In a review paper (Bianco, 2013), the author emphasizes that to truly assess risks, it is necessary to introduce distinctions in what he calls "The Graphene Family Nanomaterials" (GFN).

> Are therefore GFNs safe or toxic? The results available show that this new nanomaterial might become a health hazard, but chemical manipulation can alleviate the potential risks associated with the future development of GFNs for different applications (i.e., composites, electronic devised biomedical tools, etc.). (…) In this context, this Minireview can be also considered anticipatory and it is aimed at drawing the attention of the researchers towards developing new nanomaterials. It is not possible to give a clear answer to the initial question [is graphene toxic?], but there is strong evidence that the toxic effects are modular (Bianco, 2013 pg.4995).

In this review, the author explicitly sets up an *anticipatory* agenda to know and modulate the effects of GFN. He acknowledges that there is no scientific agreement about the actual risks of graphene; however, and despite this uncertainty, measures need to be taken.

The distinction between different types of graphene was already introduced in the publication of 2012, "A Roadmap for Graphene." This document proposes to distinguish between various types of graphene based on fabrication method and desired quality (12).

This categorization was a way to frame the "product space" of graphene, which means that there will be different applications depending on the quality of the material. While this is in principle a technical distinction, it was used by graphene actors to discuss risk-related issues in the public sphere. One publication triggered a (small) media and public controversy about the risks of graphene. This paper addresses the potential environmental risks of graphene oxide (GO)[63] (Lanphere, Rogers, Luth, Bolster, & Walker, 2014), arguing that there could be effects to the enviroment due to the release of this material. A series of specialized media websites and technology bloggers referred to the issue, which fuelled an online discussion. A response came from the GSA, who issued the following statement via its Twitter account (13):

While this statement is part of a broader discussion, it highlights how the GSA attempts to contain possible concerns about the risks of graphene by framing and shifting the

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62 A quick search in Scopus for the terms "graphene" + "risk" shows a steep growth of publications starting from 2013. However, in total these are not more than 200.

63 Graphene Oxide (GO) is produced by the oxidation of graphite oxide. In contrast to graphite oxide, it is composed of a few layers and monolayers of flakes of graphene. In contrast to graphene obtained by other methods, GO works as an electrical insulator. Nevertheless, it is particularly interesting as an alternative to the mass production of monolayers of graphene, a process that is still expensive and troublesome. (Source: http://www.graphenea.com/pages/graphene-oxide)

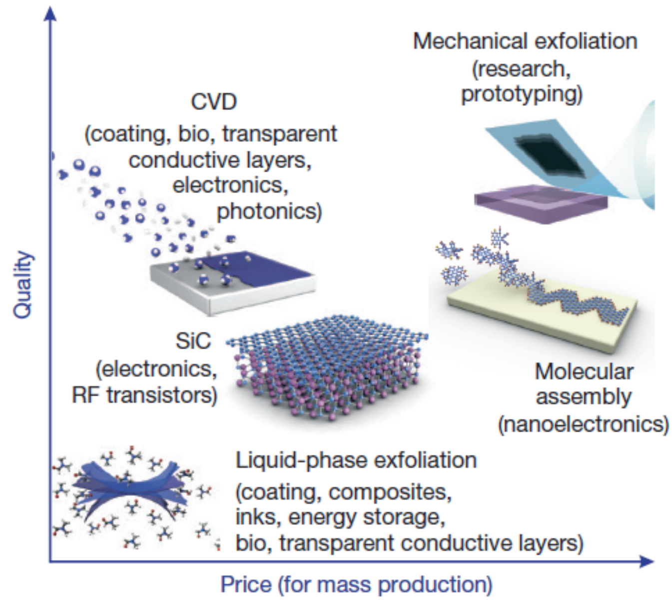

Figure 12: Various types/qualities of graphene and their possible applications as determined by the form of fabrication. (Novoselov et al, 2012)

Figure 13: Tweet by the Graphene Stakeholder Association account in relation to a publication referring to graphene oxide's possible environmental toxicity.

discussion to what is and what is not graphene. This implies that, before assessing risks, it is necessary to make clear what we refer to as graphene. This type of argument follows the logic introduced earlier, in which risk assessment is tightly bound to categorizations.

The GSA, as a self-defined independent and non-profit organization,[64] has at the core of its activities the coordination of efforts for the development of standards, which they consider to be an essential step in creating a "graphene ecosystem." In this context, they developed a partnership agreement with the National Physics Laboratory of the UK (NPL) with the purpose of accelerating this process. Together, they have been involved in discussions with ISO/TC 229[65] and other standardization committees. Appropriate standardization is considered essential in the structuration of graphene as a technology and for enabling its market. This requires adequate definitions and measurement techniques, and is at the core of the concerns of industrial actors.

A member of NPL[66] describes how the process of development of standards needs to be carefully orchestrated to respond to the present needs of the industry, but also to account for what is yet to be known.

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64 The GSA is a US-based association, initiated by a set of consultants and venture capitalists with previous experience in nanotechnology and nanobusiness. It introduces itself as a non-profit association aimed at the responsible development of graphene. The association has successfully organized business meetings and engaged with important companies both in the US and in Europe.

65 ISO/TC 229 is the technical committee of ISO dedicated to the development of standards for nanotechnologies, which includes definitions for graphene.

66 One interesting aspect is that NPL could not take part in the work on standards of the graphene flagship because of the way in which the flagship calls are structured. The section on metrology of NPL took part in the initial flagship call, with work that used graphene for specific measurements. Because the flagship requires new scientific members to belong to an institution different from those that are already partners, (be it university, company or other), a different branch of NLP could not officially take part in the flagship.

> You know it's a compromise, as with anything really. So you really have to get it right in the right slice. Graphene is sort of fast moving and in a high profile area, so maybe it is early (to develop standards), but some people were looking at doing standardization in graphene even earlier, so it kind of restarted, the work really started at the end of 2012. And you don't wanna start with standardization too early, so let's say with fast moving fields like graphene, if you would have started in 2009 it would be out of date by 2012 and will constrain the industry. The whole point of standards is to enable industry. The thing is that now the industry needs standardization, now. That's why it's been happening last year, because it's actually really needed. And of course there will be things in the future that will need to be changed, things evolve over time, (…) But the problem can be if you start with the wrong assumptions, maybe as it would have happened a few years ago you would have to move away from that particular document. Probably it is a good time to be doing it. If it happened any earlier you probably would have had a standard you would not be so happy with, we are also getting a lot of input from industry. Now it is a time when there is a lot of graphene companies popping up so you get a lot of engagement from industry itself, and this happens when academics move into industry (Interview 5, standards organization, January 2014)

In the quote, this researcher argues that standardization is a process that is constantly co-evolving with its context, that it is necessary because it introduces path dependencies. In this sense, the ability to either enable or constrain the benefit of a particular actor is a temporal one: early standards constrains, but standards – at the right time – are an absolute need. In this sense, the practice of developing standards is inherently about negotiating expectations about what will happen and who will benefit from it.

The emergence of concerns about graphene can be understood as the result of generalized expectations about the inherent risks of new materials and new technologies. Such generalized expectations are accompanied by more or less established practices to assess risks, accompanied by the development of standards and definitions for the material. Risk assessment procedures are well established among projects such as the flagship. This is not the case for industrial actors, which recognize the importance of the practice but do not have pre-structured procedures to address it. In both cases there are "concerns about concerns," the expectation that there will be public concerns about the technology and this is associated with the need to control public perception about graphene and its possible effects. The assessment of risks is limited to a specific expert community, in a clearly defined practice in which scientific methods are used to measure and estimate the possibilities of these risks. This is then connected to regulators, who are responsible for providing the framework for the management of graphene. Within this seemingly straightforward process, it is first necessary to define what is and what is not graphene. While such structured and clear practices aim to reduce uncertainty, at the core of the risk discussion is a highly contested issue: the definition of a material and the development of standards. As it has been the case for nanotechnology in general, particularly carbon nanotubes (Bowman & Hodge, 2006), providing definitions is a highly contested issue. In this respect, associations such as the GSA or the Flagship act as mediators (or lobbyists) for the interest positions of each of their parties.

4.5. Discussion

This paper has described the emergence of graphene as a techno-scientific field, by focusing on specific instances during its development across four spaces: high profile science, large-scale public funding, emerging technology markets, and risk management. We have shown how this field is configured through different anticipatory practices that are performed at different times, mobilizing actors and expectations, and enabling coordination. We have argued that this process and its performativity can be understood through the notion of assemblage, which moves through different spaces. While it keeps some of its central elements, (e.g. graphene as a disruptive technology), it adopts some characteristics of each space it moves through. There is a temporal evolution, but these spaces also co-exists and shape each other, and we observe that discourses as well as anticipatory practices of different spaces feed back into each other.

In particular, we show how different anticipatory practices shape expectations in graphene. These practices show different kinds of performativity, understood as the process by which statements and their world are co-produced, mediated by specific anticipatory practices. We show how high impact journals perform an important role in constituting and coordinating an academic field. This is not just providing guidance to actors, but defining the actor community that is involved in the field. This performativity relates to the notion of the promise-requirement cycle as introduced by van Lente (1993). However, there is a second type of performativity that refers to the way in which these journals, particularly Nature, frame graphene in terms of its societal and economic benefits. In this respect, and particularly through editorial work, the field is defined in its techno-economic aspect. This second form of performativity can be referred to as what Skøjsvold (2014) has called "transformative" performativity, in which futures act through virtual domestication processes, transforming or changing ideas about what the technology could be. In the case of the flagship application and its research roadmap, the effect of this *explicit* anticipatory practice goes beyond the coordinating effect that is often attributed to these instruments. What it produces is the arrangement and crystallization of a field, at both the discursive and actor levels, creating inclusions and exclusions, and structuring spaces (Kearnes, 2013; McDowall, 2012). The performativity shown by intermediary organizations is manifested in its most "Callonian" sense by helping to constitute markets for graphene. We show how this process is partly orchestrated by intermediary organizations, who mobilize and make sense of the figure of the hype, and by doing so create certain specifications and requirements that shape the types of products, companies and forms of value that compose the market for graphene. Lastly, "concerns about concerns" trigger the use of well-established risk assessment practices, activities aimed at risk management. At the same time such an approach confines a broader discussion about the potential risks of graphene. While the practices of risk assessment are well established, they are performative in the sense that they organize other innovation actors to act with respect to the management of these risks.

More generally, we offer some reflections in relation to how a practice approach contributes to the study of expectations in S&T, and to understanding emergence of technology fields. The first aspect is that a practice approach highlights the ways in which expectations are produced. There has been little research that pays attention to the context and the means by which expectations are created, circulated and shared, and the different material and institutional settings in which such practices take place. We show how this "expectation work" happens in specific contexts and that the way in which expectations are produced matters for its performativity. It matters because the practice itself has a certain legitimacy as it is institutionalized in a specific space, enabling certain forms of circulation of expectations. Secondly, the way expectations are produced varies across what we call "spaces," roughly defined as different actor groups and their contexts. These practices have the ability to connect, transform and create spaces, either via the expectations they produce or through the translation of practices into a different space. Furthermore, the performativity of a practice might change in a different space, as a result of a process of co-production. We have also introduced the notion of an assemblage of anticipatory practices. The attention to "assemblages" stresses the fact that the effect of a practice also relates to its operation in combination with other practices. It is the constant articulation and rearrangement of practices that shows performative effects, and constitutes an emergent field.

Lastly, we have made reference to "hype cycle" as a dynamic that is often observed in emergent technologies. We can think of these hypes in terms of an assemblage of practices that move and expand through different spaces. We see that this "wave of over enthusiasm" starts from science, moves to policy, and then the market. While there is a strategic action of actors to connect between these different spaces, (i.e., it is necessary for scientific actors to obtain public funding, and it is necessary for policy makers to make evident the societal relevance of a technology), there are also unintentional effects that emerge from the arrangements of these practices. In short, the properties of this assemblage are more than the sum of its parts. Similarly, a hype is more than the result of the strategic actions of innovation actors; there are collective – and unintentional – effects, partly as the result of anticipatory practices moving through different spaces.

5. Doing is believing: how material practices shape the future in 3D printing (*)

(*) A version of this chapter has been published in S.NET volume (2015).

Abstract. Recent years have witnessed the emergence of 3D printing framed as a revolutionary and transformative technology. The development of consumer 3D printers, as well as the emergence of FabLabs has fueled a wave of expectations and (over) enthusiasm around the technology. Expectations around 3D printing address not only what the technology may deliver (economic growth, solution to societal challenges, radical innovation) but also how the social arrangements around the technology offer new possibilities. This is a narrative where innovation occurs because of curiosity, 'tinkering' and enjoyment in an open, collaborative and distributed way. This narrative corresponds to specific imaginaries and shared visions of technology development that are able to shape technological paths. This chapter studies the material practices in which these visions of 3D printing are embedded. We explore and compare how three companies actively shape and anticipate the future of 3D printing by embedding and mobilizing expectations in specific material practices. These are guided by a combination of logics that move between open-source and techno-economic. We show that these two different logics are accommodated within the same practices, and are aimed at fulfilling parts of a similar vision. The analysis provides preliminary indications of how logics of innovation evolve and shape anticipation in the case of an emerging technological field.

Keywords. 3D printing, sociology of expectations, anticipation, anticipatory practices.

5.1. Introduction

In recent years the growth of the consumer or desktop 3D printer has been explosive – analysts estimate a growth of 346% between 2008 and 2011 (Wohlers, 2014). To the date, there are no concrete estimates of how many consumer 3D printers are "out there", since many of these machines are self-produced by makers and 3D printing enthusiasts. As an indication, on January 12th, 2015, 3D Hubs, a service of online 3D printing based in the Netherlands announced that they had connected the 10,000th 3D printer to their worldwide network of printers (3D Hubs, 2015b). This was only about a year and a half after the company started its service, now turned into a large network of interconnected 3D printers across more than 140 countries. This is only one sign of the explosive growth in the number and types of available machines, with hundreds of small 3D printing companies founded via crowdsourcing sites and large companies entering the 3D printing business.

As the number of machines has grown, so have the expectations. The 3D printer became the new favorite of the media, being associated to grand promises and visions about prosperity and disruptive innovation. It is presented as the technology that will enable the Third Industrial Revolution creating a wave of disruptive innovation, local production and the end of scarcity (C. Anderson, 2012; Rifkin, 2011). However, the expectations about a future where "anybody - who owns a 3D printer - can make almost anything" go far beyond the current possibilities enabled by the technology and only exist in the imaginaries of those who engage with it. In fact, the increasing attention the field has received has also been accused of overpromising and hype (Bass, 2013).

In this chapter, we investigate the material practices deployed by a set of actors in the 3D printing field in order to anticipate particular futures for the technology. By material practices we refer to practices that are not *explicitly* anticipatory, as for instance foresight would be, but rather practices of designing, organizing, sensemaking and financing of technology, which are usually not considered as anticipatory in the first place. Rather, these practices, which are part of innovation processes, contribute to shape the future of 3D printing – or particular aspects of it, such as the development of software, hardware, standards, forms of transaction, etc.; - by referring to, voicing, mobilizing or challenging expectations, either through discourse or embedded in material developments (prototypes, reports, standards, etc.). We furthermore show how these practices are guided by two different but complementary logics that move between techno-economic and collective experimentation regimes. As our guiding research question we ask *which material practices shape expectations about 3D printing, and which logics guide these practices?*

The chapter develops as follows. The next section introduces the historical context of the development of 3DP, in particular related to the RepRap project, FabLabs and maker communities. The third section presents the framework and the fourth section our methodology. The fifth, empirical section analyzes three actors and the material anticipatory practices these actors engage in to promote their visions about 3D printing, and the logics that guide them. The last section reflects and discusses the relation between the variety of practices and the logics that guide them.

5.2. Background

3D printing as we know it today is a derivative of a 20 year old industrial technology called Rapid Prototyping or Additive Manufacturing. As the name suggests, it is a technology that produces 3D structures layer by layer, in contrast to subtractive manufacturing techniques. A variety of materials can be used, ranging from plastics to ceramics and metal. In its origin, 3D printing was used for the production of prototypes for industry and now is more and more moving into the production of everyday, yet 'customized' and unique, objects (Berman, 2012). For many years 3D printing machines occupied a niche market until the concept of the "consumer 3D printer" emerged with the RepRap project.[67] For this reason, we suggest to distinguish between the industrial and the consumer realms of 3D printing (Hague & Reeves, 2013). In the remainder of the chapter we will investigate practices associated to 3D printing (3DP) that is, consumer-oriented technologies.

The RepRap project, initiated by Adrian Bowyer in 2004 was aimed at producing an open source 3D printer that would in the long run be able to reproduce itself - hence the RepRap "Replicating Rapid Prototype" name (Bowyer, 2014). The development of this project has been described in detail elsewhere (de Bruijn, 2010; Söderberg, 2013, 2014; West & Kuk, 2014). What is important is that the RepRap project, by being framed and developed as an open-hardware project, spurred collaborative and open innovation across a community of hackers and makers that resulted in a desktop size 3D printing accessible at a much lower cost than the existing industrial 3D printing machines. As a consequence, it opened a complete new market beyond the industrial prototyping applications. Today, most of the machines that fall into the category of consumer 3D printers derive from the RepRap Project. Understanding this context is essential to characterize the way the future is portrayed by 3D printing actors today.

The 'open source' aspect of the RepRap machine was central to Bowyer's vision. All the design instructions and files, as well as the accounts of the process of construction were shared online via the RepRap wiki and blog, and anybody could get involved in the project and develop their own RepRaps. These requirements were directly in line with the vision of "wealth without money" that Bowyer saw for the machine. Following this logic open source "was the only sensible thing to do" (Bowyer, 2007) since the final aim of the RepRap project was to spread the technology all over the world and displace existing manufacturing paradigms, democratizing and distributing production (Söderberg, 2014).

In the course of this project, a growing community of 3D printer enthusiasts and makers was formed, connected through the RepRap site, who developed various noncommercial and commercial machines. The earliest and most well-known of these open source startups was Makerbot. This company spun off from the RepRap project in 2009 and quickly became the market leader of desktop 3D printers. They created a website called **Thingiverse**, an online community for sharing user generated content and designs compatible with open source hardware, and which later became the major hub for 3D designs. Makerbot sold open source assemble kits for 3D printers that helped to spread the RepRap concept across various communities (West & Kuk, 2014).

In its early stages, Makerbot was aimed at making information and the technology flow as much as possible by making it accessible to a broader community of makers and

[67] Although the RepRap Project is the most visible, there were earlier attempts to develop a consumer 3D printer: Fab@Home (http://www.fabathome.org/) and Desktop Factory (a company acquired by 3D Systems in 2009).

hobbyists, who could also improve the machine. Thus, keeping the software and the design open source was important. This created a tradeoff since it required highly skilled users and long-time investment to make the machines work properly (Söderberg, 2013). This was not a problem for the makers, who enjoyed tinkering and suggesting improvements, but it was at odds with the intention to expand it to a broader public. In this context, Makerbot started to acquire a more and more proprietary (closed source) strategy, also as a means to differentiate itself from other RepRap based companies (West & Kuk, 2014).This process culminated in 2013, when the large multinational Stratasys acquired Makerbot (Sharma, 2013). This was the result of a process where both the machines, and the sharing platform Thingiverse became more and more proprietary, creating an adverse reaction from a large part of the 3D printing community. This acquisition was a disappointment for the community that supported Makerbot, not only as consumers but actively building the technology and its ecosystem, who saw their openness as central to the commercial success of Makerbot and not as a competitive disadvantage (Dickel, Ferdinand, & Petschow, 2014)

While this is the specific story of Makerbot, it is important understanding how the expectations about the technology have unfolded. It shows the general tension in the field between ideas of democratizing innovation versus economic logics. As the technology has become more popular, actors have changed their strategies, moving away from their original ethos. Nevertheless, the basic promise of the 3D printer – and its limitations – remains almost the same since the 2004's RepRap manifesto: In the long run, the technology will enable anybody to make almost anything. In practice, it is possible to print simple available designs but actually developing own prints requires non-trivial design skills.

There is a second component that adds to the promises of 3D printing which is the emergence of shared workshops for digital fabrication, particularly FabLabs. Around the same time the RepRap project was initiated, Neil Gershenfeld at the Center of Bits and Atoms in the MIT started his FabLab initiative. Fablabs are workshop spaces that provide the possibility to "make almost anything", and which quickly spread across the world. While a FabLab includes various fabrication machines, the 3DP became quickly the "crown jewel" of the FabLab (Lhoste & Barbier, submitted) although it was never part of the official chart of machines.[68] However, the "magic" of the 3DP and the effect it had on those who saw it made it an emblematic component of FabLabs (Troxler, 2014, Walter- Herrmann and Büching, 2014).

These two developments are intrinsically anticipatory. The RepRap project has been called "a roadmap to the transcending of the existing market society" (Söderberg, 2014)

68 According to the FabLab foundation, to qualify as a FabLab there are certain requirements of tools and processes. There is a list of critical machines and materials that should be found in every FabLab in order to make their operation reproducible across the world. This list of machines did not include a 3D printer in the beginning.

while FabLabs have been defined as a roadmap to "digital fabrication" (Gershenfeld, 2015). By framing these initiatives as "roadmap" it is made explicit that the construction of communities around workspaces and sharing practices is paving the road for specific futures. These two projects are not framed as something for today, but as the road to a different techno-economic context. In this future, the digital merges with the material, atoms and bits are indistinguishable enabling anybody to make anything, anytime, anywhere (Söderberg & Daoud, 2011).

5.3. Framework: Anticipatory Practices and Logics

This chapter explores the material practices that embody expectations about 3D printing, and how these are used to further mobilize these expectations. We want to investigate how the context in which actors are embedded affects the expectations that are produced, and how the way they are produced matters for their performativity. We argue that these expectations are performative because they affect, change and guide social processes occurring in innovation fields (Borup et al., 2006, van Lente et al., 1998).

For new and emerging technologies, promises, visions and expectations play an important role in guiding activities in contexts of high uncertainty (Borup et al., 2006; Rip, 2012). Anticipation is a process where the present is transformed, intervened in and ultimately governed in the name of the future (Adams et al., 2009; B. Anderson, 2010). An important part of the process of anticipation is the mobilization of expectations and visions in order to legitimize, guide and coordinate particular futures. In this chapter we describe a process of anticipation happening in 3D printing, and the anticipatory practices through which it takes place. We focus particularly on the relation between visions, expectations and these specific practices that give shape to the "futures" of the technology.

We begin by clarifying the differences and relations between these three categories. In general, *expectations* are statements about future conditions or developments that imply assumptions about how likely these are supposed to be. With a focus on expectations related to science and technology, technological expectations have also been defined as "real time representations of future technological situations and capabilities" (Borup et al., 2006), with collective expectations being those that are collectively shared by a community (Konrad, 2006b). Besides *expectations* which may be confined to particular technological developments or future states, *visions* refer to more or less coherent packages of potential future states (Berkhout 2006; Eames et al. 2006). Visions usually imply more normative connotations, while not necessarily assessments of likelihood or plausibility. Usually visions are related to a series of expectations; for example, the *vision* of distributed manufacturing associated to 3D printing is accompanied by *expectations* about the roles certain actors should play, the kinds of requirements that should be fulfilled by the technology, among others (Parandian et al., 2012; van Lente, 1993). Visions and expectations are part of a process of *anticipation*, in which visions, expectations and other forms of knowing the future, are mobilized to change the present in the name of the future, through specific material practices (Anderson, 2007).

Expectations are produced by a range of *anticipatory practices*, invested, formalized and deployed for knowing and acting upon futures (Anderson, 2010). These anticipatory practices encompass a wide range of activities, from explicit forms of anticipation, such as foresight, to every day practices of innovation actors such as filing patents, scientific publications, conferences, grant applications, among others. We consider these practices anticipatory if they refer to, mobilize and/or shape expectations about the technology, either as part of discourse or embedded in material developments such as prototypes, press releases, legal standards, software tools etc. This approach highlights that expectations are "conducted in material settings" (Kearnes, 2013, Brown and Michael, 2003) and that they are not just the result of explicit tools but instead a component of many innovation practices. By doing so, this perspective stresses the relation between the context, expectations and the way they are produced. Different practices produce different types of expectations, content wise, and implicitly with regard to the possibilities (and requirements) for action which are created for actors in the field. Therefore, we suppose that the performativity of these practices differs.

We can think of this relation at the actor level: innovation actors deploy expectations for specific purposes, such as mobilizing resources or coordination. At the same time, there is active shaping and use of these expectations by actors, with effects that go beyond the original purpose (Konrad & Alvial Palavicino, forthcoming). This reflexive relation is embedded in material practices, as we will show in the remainder of this chapter.

These material practices are quite diverse, and it is interesting to understand what leads a certain actor to engage into a particular set of practices and how these practices are coherently arranged. We would argue that the type of practice an actor deploys relates to the conditions in which these actors are embedded. To understand these conditions we use the concept of *logics*, which broadly refers to a set of rules, or grammar that enables and discourages certain practices and their combinations (Glynos & Howarth, 2007). It refers to the guiding principle that brings these practices together in order to act in relation to a future. By introducing logics, we want to highlight two aspects. First, the ways of acting upon the future are not given but need to be constantly reenacted (Anderson, 2010). Second, the constant reenactment of practices also leads to spaces for contestation and innovation, which may introduce new practices and enable evolution and change.

How to think about the logics that guide innovation processes? It has been argued that current innovation regimes move between two modes, or two logics: the *regime of economic techno-scientific promises* and the *regime of socio-politics of collective experimentation* (Felt & Wynne, 2007). These two regimes characterize two types of innovation: on the one hand there is a linear and centralized model of innovation; and on the other a distributed, collective and open one. In practice, most innovation processes are located somewhere in between these two regimes. We will take these two regimes as a starting point to study the logics of anticipation in 3D printing.

We propose that there are two logics that guide anticipation in the field of 3DP: an *open-source logic* and a *techno-economic logic*. These two logics can be considered as "ideal types", in the sense that they do not represent exact instantiations of social phenomena but idealizations of them (Weber 1988, p.190).[69] The selection of these logics as a starting point for the analysis relates to the background history of the field (section 2) and the distinction between regimes of innovation introduced earlier. While further characterization has to be empirically grounded, we will argue that processes in 3D printing situate somewhere between these two logics. We will shortly describe each of them.

5.3.1. Open source logic

This first logic relates to what we have referred to before as regimes of collective experimentation. As mentioned earlier, the RepRap project originated in communities engaged with open source hardware and software. To understand the cultural significance of the open source software, Christopher Kelty introduced the concept of "recursive publics" (2008), by which he means that the development of open source (in his case, software) is related to a set of practices in which technical and legal developments are used to discuss about the future possibilities of a technology. Recursive Publics is then the term given to these communities, defined as "a public that is vitally concerned with the material and practical maintenance and modification of the technical, legal, practical and conceptual means of its own existence as a public; it is collective independent of other forms of constituted power and is capable of speaking to existing forms of power through the production of actually existing alternatives" (p.3). These recursive publics are brought together by a logic in which power is challenged and contested mainly through the construction of technical alternatives, rather than by rhetoric or social means. This is clearly the case for the RepRap project, in which the vision of "wealth without money" is expected to challenge capitalism not by social revolution but by the use of technology (Bowyer, 2007).

Actors do not only share collective expectations about the technology, but also use the technology itself as a means to think, speak, tinker and actively anticipate futures. Futures are not just imagined, they are actively created. The geek public discusses, shapes and enacts their visions of the future less by rhetoric and more through material practices.

69 This understanding of ideal types follows the analytical conception of ideal types by Max Weber. This does not exclude that these ideal types, in particular the open source logic, are perceived as a normative ideal by actors in the field.

For geeks, the aim is to do rather than to discuss; "ideologies" are mediated by the socio-material practices that sustain them (Kelty, 2008).

Starting from this notion, we define an *open source logic,* which refers to the possibility of opening spaces for change and discussion enabled by technical and legal developments. The materialities emerging from these practices are recursive: they are explicitly and intentionally subjected to constant change.

5.3.2. Techno-economic logic

The second logic that we find in 3DP is related to the regime of economics of techno-scientific promises, and we will call it a techno-economic logic. Today, 3DP has become much more than a "geek" technology, moving into the broader consumer sector[70] which is guided by dominant economic logics.

One of the characteristics of this economic logic is that new technologies are associated to promises and expectations constructed in relation to a problem to be solved (e.g. a societal challenge) and their possibilities to contribute to economic growth (Joly, 2010). New technologies, such as nanotechnology and synthetic biology, are presented and legitimized as if they could solve many, if not all problems faced by society without fundamentally changing the conditions that lead to these problems.

These promises refer to narratives of breakthrough, progress and urgency, in which the possibilities of a technology are balanced against its threats and risks. Specifically, practices that develop under this logic aim at the quantification and specification of futures (such as forecast, scenarios or Delphi) to legitimize specific paths and methods of intervention, governance and control. Overpromising is also a feature of this logic. In this dynamic of promises and concerns, new technologies also need to be controlled and regulated (Fordyce, 2015; Record et al., 2015). A techno-economic logic enables practices in which the future is referred to with a sense of urgency and competition, and in which the aim is to intervene as early as possible in order to achieve a promise while avoiding potential risks.

We argue that the anticipations found in 3DP move between these two logics, open source and techno-economic. Similarly, the maker movement moves between four self-definitions: bourgeois pass time, innovation in education and technology, new renaissance reconciling liberal arts with science and engineering in a contemporary and playful way, and the new industrial revolution. But in practice the movement swifts between the first two definitions, while the latter two are just rhetorical means, romantic or rebellious (Maxigas & Troxler, 2014). However, rhetorical as they may be, these ideas guide and articulate some of the anticipatory practices in which actors in the field engage. Practices move between

70 Large companies such as Stratasys and 3D Systems have expanded their operations into the consumer domain.

these two different logics, which makes the articulations about the future of 3DP a complex mixture of visions and expectations.

5.4. Research Questions & Research Approach

As we have introduced earlier, the purpose of this chapter is to enrich the discussion about anticipation in 3DP by looking at the material practices through which the future is anticipated. To do so, our main research question is *How are expectations about 3DP embedded in material practices and what logics guide them?* Specifically, we want to study material practices and their relation to the future (as being informed by expectations, but also being aimed at shaping expectations) and the logics that guide these practices. Last, we want to reflect on the way how diverse practices, related to different logics, contribute to shape the field of 3DP.

To analyze these questions, we took a case study approach. These cases are build around 3D printing companies based in The Netherlands. Methodologically, we draw on 23 semi structured interviews (company CEOs, technology consultants, researchers), participants observation (attending 2 conferences and one trade show) and digital ethnography (Coleman, 2010) in selected 3D printing media sites, the crowdsourcing site Kickstarter, blogs and relevant social media.

While the actors presented in these cases only represent a fraction of the 3DP field, our analysis shows how diverse material practices and logics can be. We particularly focused on practices that are not explicitly anticipatory (as it would be the case of foresight) but rather material practices that have an anticipatory component. We analyze three companies that represent a wide range of positions, from open source to closed business models: Ultimaker, 3D Hubs and Printr. Two of these three companies are well know globally. Ultimaker is one of the oldest and leading companies in consumer 3D printers worldwide, and 3D Hubs is a recently developed platform that has had enormous success, being present in around 150 countries. These two companies are recognized for their contributions to innovation in consumer 3D printing.

Based on this data, we identified key practices in which these companies engage and their relation to visions and expectations. For identifying an anticipatory practice we searched for cases in which claims about the future (visions and expectations) were used to give meaning and to frame the practice, and in which the practice is meant to have an effect on the conceptions about the future of 3DP for a certain community of actors. For each anticipatory practice, we focused on the associated expectations, on the means by which it is constructed, and its effects in related communities. We classified these practices with respect to their guiding logic, be it open source, techno-economic or a combination of both.

5.5. Doing is Believing: Anticipatory Practices and Logics in 3DP

In this section we describe the material practices by which a set of actors in 3DP develop and embed visions of the technology. We show how these practices speak to different logics and the contradictions that might emerge.

5.5.1. From RepRap to the Ultimaker: the future is about sharing

Ultimaker is a consumer 3D printing Dutch company founded in 2011, “spun out” from the RepRap Project. It is one of the most popular companies for 3DP in Europe (3D Hubs, 2015) and well known around the world. The company itself has strong roots within the maker and the FabLab movements. The founder of the company, Erik De Bruijn was, since 2008, part of the original core team of the RepRap project, when he started producing his own RepRap machines.[71] He met the cofounders of the company, Siert Wijnia and Martijn Elserman while being directly involved in setting up one of the first Fablabs of the Netherlands, Protospace (Utrecht). For these communities, values of tinkering, sharing via open source hardware projects and self-empowerment are important and shape their practices (Nascimento, 2014).

From his first engagement with the RepRap, De Bruijn explains how it was important for him to actively construct the meaning of the technology. This was not just about rhetoric, but work such as building your own 3D printer in cooperation with a community. In this context the company was founded, seen as part of the developments that will fulfill the promise of 3D printing. As explained by De Bruijn, this is “*in a way that is I guess less morally driven, but it is actually a technology that is empowering people. (...) the companies that made it more accessible made something different than what the hackers and the tinkers made for themselves*” (Interview 7, Erik de Bruijn). This is how this company keeps the vision of 3DP alive and feasible while being pragmatic about its normative commitments.

We describe two of these anticipatory, material practices: the sharing of source files for their machines and the developing of a sharing license for 3DP. We will argue that these two practices respond mainly to an open source logic.

Sharing the Ultimaker 2 The Ultimaker defines itself as an open source “inspired” company[72], concerned with meeting the expectations of their “community” of users. Being identified as open source is an important aspect in order to engage with a particular community and enable their vision of 3DP. Open source practices are essential for spreading 3D

71 At the time he started working in the project he was a Master's student in Economics. He wrote his thesis in relation to the RepRap project that gave him a good overview of the market of 3D printing.

72 It is out of the scope of this paper to assess if the Ultimaker is or is not really open source, but rather, what does it mean to define a company as such.

printing and encouraging open innovation.

In this context, the source files for the Ultimaker 2, the latest printer released by the company, were made available in the sharing site YouMagine and GitHub[73] six months after the release of the Ultimaker 2 in March of 2014 (Park-On, 2014). The release of these files was referred to numerous times in specialized media, blogs and forums. The files were released under a CC BY-NC (Creative commons non-commercial) license, which enables the use of the files but not to profit from them. As framed in the release site in YouMagine,

> It is our firm belief that sharing knowledge does not mean losing knowledge. On the contrary, we learn from each other, inspire each other and use each other's knowledge to create even better products and develop impressive innovations world-wide (Ultimaker, 2014).

Ultimaker users positively received this action. However, some blogs and forums questioned the open source status of this particular practice. We looked at the discussions occurring in the YouMagine blog (Ultimaker, 2014) and in the RepRap forum (RepRap, 2014). In these forums, the open source status of this release was questioned. Some users questioned if a six-month delay for the release of the files, under a non-commercial license, could still be called open source. Strictly speaking and borrowing directly from open source software definitions, open source licenses should allow the commercial use of the files that are being shared (OSHWA, 2014).

It was questioned if this release was motivated by business interest instead of the open source ethos (comment by bld, YouMagine blog, May 2014). Other users would argue that this indeed qualified as an open source practice, because the definition of open source had to be rethought to be useful to companies that wanted to invest in R&D, in a context of growing interest and competition among 3DP companies (comment by Dani Epstein, YouMagine blog, December 2014).

The way the “community” discussed this particular practice speaks to questions of the future of open source moving into hardware and its relation with the global 3D printing industry. For the Ultimaker, releasing the files of the Ultimaker 2 is a way to make clear their own commitments with the way they think the industry should develop to ultimately, fulfill the 3D printing visions. For users this open source release can be seen either as a marketing practice, or as a legitimate transition to how open source hardware from a company perspective. More fundamentally, it is these “open source hardware” practices that are questioned, rethinking how they should be embedded in an environment subjected to market demands. Thus, the specificities of what is released, when and how are relevant and help to re-define the practice itself, as well as the relation between open source and the vision of 3D printing.

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73 GitHub is a web-based repository for publishing and sharing source code (software), but also a social networking site for programming.

3DP Sharing license A second practice in which Ultimaker engages is the development of a sharing license for 3DP. In order to build and enable 3DP, Ultimaker supports the development of the site YouMagine, an "online community for everyone who's eager to explore the world of 3D printing".[74] This platform was built in response to the changes in Thingiverse, the original sharing site associated to Makerbot. Following Makerbot acquisition by Stratasys, Thingiverse modified its Terms of Service (ToS) to an irrevocable license of broader scope, causing some disappointment in the 3D printing community (Dickel et al., 2014). The members of the community argued that the platform was not open anymore and that it has betrayed their ethos (Moilanen, Daly, Lobato, & Allen, 2015). A number of alternatives emerged, including YouMagine. De Bruijn explains his motivation to build this platform.

> I'm personally on a mission to encourage people to share more, to empower others and to allow global collaboration. The technology to create things, in the hands of the many can lead us into a new age of innovation and prosperity. YouMagine could play a large role in this. (...) From before it became part of Makerbot until recently, I've been a huge advocate of Thingiverse. Me and many maker/RepRap friends believe we've helped make it happen. But now Thingiverse isn't what it used to be. There has to be a good place to share, and I intend to make YouMagine as friendly as possible and stick to our ideals (Peels, 2014b).

He emphasizes the need to enable a platform for people to share. However, these are not sharing platforms just for today. They are built and transformed in order to fulfill a specific vision of tomorrow, a vision about collaborative innovation. Currently, YouMagine works as many other online platforms[75] (such as Instructables, among others) where members, via free registration, can upload their 3D designs and share them with other members, or use the ones available. It is expected that in the future new functionalities will be enabled in the site, in order for YouMagine to become a true sharing platform. It is envisioned as a site that enables and encourages collective projects from all over the world to flourish, such as the e-nabling project (Dickel et al., 2014). There are two requirements: to enable a group functionality in the site and to develop a license appropriate for these sharing projects. The community manager of YouMagine explains the logic of this license, how it relates to the Ultimaker's vision of 3DP and why none of the existing licenses fulfills this requirement. He explains how a future of sharing and innovation needs to be supported by appropriate technical and legal means, and once these are in place sharing will happen, almost naturally. This new form of sharing is central to the vision

74 https://www.youmagine.com/

75 Gillespie (2010) shows that these online platforms fulfil different discursive roles, shaping the politics of information circulation through the Internet.

of 3D printing, up to being referred to as the "killer app of the technology" (Interview 6, consultant, 22-10-2014).

> We hope we make a license that would work given what we think the future is. (...) Our goal is to make people share, this is the new thing, the killer app. Cause the whole one-guy-making-one-thing everyone else is already doing. One company locking up one design of technology everyone else is already doing it, so we are gonna do the opposite, which is don't lock anything up and let everything be available for remix. Copy-paste all the things. (...). We are not very philosophical about it but we are very goal oriented towards that. Anything not sharing it doesn't make sense for us. [Furthermore, later he adds] Our vision of the future is people sharing, and that's why we do it. We hope we kind of make a license that would work given what we think the future is. (Interview 6, consultant, 22-10-2014).

In March 2015 a beta version of the sharing license, named 3DPL was released (Peels, 2015a). The developers explicitly asked for feedback for this version from the broader community of 3DP users and enthusiasts. The license addresses issues of Intellectual Property, and encourages sharing and remixing, making explicit the rights and responsibilities of those who are part of this remixing process.

The 3DP community received the release of the license with some skepticism. Users that responded to the release questioned the need of yet another open source license, when there are other licenses available such as GNU or CC.[76] Users argue that there are already many private actors releasing their own licenses and this seems like a marketing tool (YouMagine.com, *Leigh Dodds* 6 March 2015). These users also questioned whether some specific aspects of the license would enable sharing, such as the attribution sign and the penalty system. The license proposes to add to each print a sign that enable consumers to track back the source and the history of production of the object, a form of traceability of 3D printed objects (Peels, 2015b).

These questions, concerns and criticisms were discussed during a Google Hangout session organized by YouMagine.[77] During this session it was emphasized that the difference the 3DPL license wanted to make was to enable sharing and remixing. This is something that will become more and more relevant in the future, when distributed innovation enabled by 3D printers, becomes a mainstream issue. Thus, developing this license is anticipatory, as they argue; this is the time when efforts are worth taking in shaping the technology, before it becomes mainstream and stabilized. However, for users this particular anticipation seems to be still too early.

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76 One unsettled topic in the open hardware movements is if the existing "open" licenses, such as GNU and Creative Commons are suitable for hardware and 3D printed objects (Greenbaum, 2012).

77 The session can be found here: https://plus.google.com/events/cntm9mtvvqjr7bok6rm9qleif2c

Ultimaker and an open source logic We have shown how two of the practices in which Ultimaker engages, the release of files presented as open source and the development of a sharing license for 3DP objects, are anticipatory. These two practices are informed by the visions and expectations the company has, and at the same time they are used as means to spread these expectations and actively shape the future in a particular way. This shows how these visions and expectations are materially embedded but it is the materiality and its context that is contested. We argue that these practices are guided by what we call open source logic because they speak to and try to change the current innovation regime via the development of technical and legal means, and this development is open (to community considerations) and recursive. For example, the release of the files of the Ultimaker 2 is not only relevant for the company itself, but it leads to a reflection about what open hardware means in the changing context of 3D printing.

5.5.2. 3D hubs and the raise of a global 3D printing community

In the last 4 years the number of consumer 3D printers available in the world has increased exponentially as well as the number of companies that produce consumer 3DP. This includes "old RepRaps in new dresses" (Interview 6, 3DP consultant, 22-10-2014) as well as innovative machines that are bringing other types of technologies[78] to consumers. In this dynamic context, another type of company has emerged, what is often referred to as service bureaus (Reeves, 2014). These companies are online "marketplace" platforms (websites) where consumers can order to print their 3D designs on demand. These companies (ex. Shapeweays, Sculpteo or i.materialize) often have their own "factories" with industrial 3D machines available and offer the service of delivery, as well as pre-made designs.

In the summer of 2013, two young Dutch entrepreneurs funded one of the newest and most innovative of these service bureaus. 3D Hubs, as the name indicates, is a platform, an "*online hub*" that "*connects people who want to 3D print with people that own a 3D printer*," anytime and anywhere in the world, promoting local production and the expansion of the use of 3DP. In order to do so, owners of 3DP sign up to offer printing services locally, which people interested in printing can access on demand and via subscription to the site. Very quickly, the website has become very successful, growing exponentially with nearly 15,000 printers listed in over 140 countries.[79]

78 In addition to FDM (fused deposition modeling) machines, which is the most popular type of consumer 3DP, in recent years other technologies such as stereolithography (SLA) have been adapted for consumer, adding also new materials..

79 This number of printers corresponds to June 2015. As mentioned in the introduction, by the beginning of 2015 this number was 10,000 printers. The variation shows the rapid growth of the 3D Hubs network. For up-to-date information check https://www.3dhubs.com/

Brian Garret and Bram de Zwart, the co-founders of 3D Hubs wanted to start a company that could really fulfill the promise of 3DP, which they defined as the local and distributed capacity of manufacturing. Their motivation was based on the assumption that the promise of 3DP of local and on demand production was not being fulfilled fast enough (Peels, 2014a). The head of community of 3D Hubs explains this motivation as giving access to 3D printing to a wider range of people:

> (…)3D printing harvests a huge potential for social reformation, and decentralization of manufacturing and thus economic power, decentralizing wealth. Current manufacturing methods centralize both the wealth and the power. So I guess most in terms of accessibility and social potential 3D printing wasn't doing much a year ago [in 2013]. So, we figured, the sales were rising already, sales of desktops machines and new technology came to market very quickly, so we thought we need to give more access to it (…) (because) individuals have half a million machines on their desktop, which is the technical potential. (Interview 19, community manager, 28-11-2014)

3D Hubs frames fulfilling the vision of 3DP as an issue of access. We will describe two of the anticipatory practices 3D Hubs engages in. The first one is creating and enabling local 3D printing communities and the second, the release of Trend Reports.

Unlocking the Hub According to the founders, to fulfill the promise of 3D printing, the local capacity of manufacturing needs to be "unlocked". Unlocking means to enable every owner of a 3DP to offer the service of local production through the 3D Hubs platform. The platform of 3D Hubs enables owners of 3D printers to open "a hub" where they can offer a printing service. Among the 'hubs' there are individuals, maker spaces, companies, associations, etc. These hubs are created and sustained by a combination of offline and online activities.

Each of these hubs is composed by many local 3D printers. In order to enable a hub to be listed in the 3D Hubs site and opened in a specific location, there is an "unlocking" mechanism. The Head of Community explains how this mechanism works:

> An early adopter, a 3D printer enthusiast, they see this rule and they are gonna ask all his (sic) friends to join, not realizing that they are building the community already. They would get 20 printers listed, (…), the marketplace as a place works, and then we unlock the community, we throw a party and there is a lot of PR, and more people come and more consumers come. This was also a growth tactic, which was also leading to the foundation of the community. And after the community is unlocked we open the position for mayorship, which is basically a volunteer who shares our vision, the things where we started and he wants to make that happen. (Interview 19, community manager, 28-1-2014)

This unlocking mechanism enables 3D Hubs to build and support and coordinate their communities, both online and offline. These communities are organized around the vision of 3DP, particularly the vision and values shared by "geek publics" of open, local and distributed production. However, their daily choices are very pragmatic and there is space for all beliefs and motives. Yet members sustain these hubs because they believe in the vision and are willing to work for it (Interview 19, community manager, 28-1-2014). The vision of 3D printing of increasing accessibility is able to accommodate divergent and diverse expectations.

This practice is central to the functioning of 3D Hubs. One of the functions of the hub is to spread their vision and specific expectations about 3DP. Some of the events that are organized in a Hub discuss recent developments in the field (materials, procedures, etc.) and keep the hub community together. This is what the company calls "the network effect" [80], against which they benchmark themselves in comparison to similar companies (Shapeways, MakeXYZ, etc). This "effect" is about being able to offer a diversity of services to one consumer based on the availability of the network, much in line with the idea of a sharing economy.

Releasing the Trend Report In order to give an overview of their market and community, 3D Hubs releases monthly Trend Reports. These reports are produced by the operation of the network itself: with almost 15,000 3D printers, it leverages the data produced from the reviews of users and owners of 3D printers. The report is constantly updated, based on an algorithm that takes and analyzes the data from the site. It is presented as authoritative knowledge about the 3D Hub's network and consumer 3D printers in general. These free reports show the growth of the network, what is being printed, the preferred machines, geographical distribution and others. The head of community explains that these reports are for free because "the data is basically from the community, they give it to us by joining the network, makes sense to give it back" (Interview 19, community manager, 28-1-2014).

These reports[81] include a ranking of the most wanted and best evaluated 3D printers (model & company) in different geographical locations, for both consumer and industrial 3D printers. To assess the quality of prints of a certain machine, 3D Hubs has created its

80 "Network effect" refers to an effect in economics, related to the value that one user of a service has for the value of that product for other people; the value of the product is dependent on the number of people using it, i.e. the network. The interviewee refers to this effect as "something we did not anticipate so fast is the whole network effect of it, so the whole accessibility of 3D printing that was a pretty clear idea, people listed it and just like Airbnb. But what Airbnb doesn't have it's a network, so you don't link the different departments in any way. We can, we have like a central brain, network, and we put like assignments in all kinds of different machines so you really get the network effect" (Interview 19, community manager, 28-1-2014)

81 https://www.3dhubs.com/trends

own standard, the Marvin figure (14). This is the print of a model based on the character "Marvin the Martian" by Warner brothers. When a new printer is added to the network it is asked to print a Marvin and send pictures of the result to 3D Hubs.[82] Because of the popularity of 3D Hubs among consumer 3D printers, and thus its trend reports, the Marvin has become the *de facto* standard to assess the quality of prints for an important part of the community.

The report (latest edition in April, 2015) shows that the 3D Hubs network is largely composed by desktop 3D printers, with a smaller portion of industrial machines. The report is used by many 3D printer companies for benchmarking purposes, and by experts and consultants in the field to assess the state of the technology.[83] It gets legitimacy from the fact that the data is produced by the 3D Hubs "community" rather than individual experts. These free reports are circulated through various 3DP news sites and are quoted as authoritative sources for the state of the industry.

At the beginning of 2015 the company also released a crowd-sourced guide to 3DP[84] based on the data generated by the reviews in their site. This report is introduced in the 3D Hubs site as:

> **Which 3D Printer should I buy?** is the most common question we at 3D Hubs are asked.
>
> We reached out to our global community of Hubs to learn from their experience and see what they thought of the 3D Printers they own. The 2015 3D Printer Guide is based on the reviews of 2,279 verified 3D Printer owners. Their collective 1623 years of 3D Printing experience coupled with 317,000 prints completed on 235 different 3D Printer models, makes this the most comprehensive guide available. (3D Hubs, 2015a)

The report is presented as the result of all the data gathered from the network and it reflects its depth and extension of the network. It comes to fill a void in relation to those newcomers to the technology who look for information about what printer is suitable

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82 For example see https://www.3dhubs.com/talk/thread/marvin

83 These reports are quoted and analysed in 3D printed specialized media such as 3dprintingindustry.com, 3ders.org, tctmagazine.com, among others.

84 It is important to note that machines are ranked based on the score given by users to each of the printers. However, the categories in which these printers are scored (materials, print quality, community, operability, running costs, etc.) are hardly comparable. Also, the number of reviews that are used to score a printer is very variable. For example, a Builder Dual Feed machine is ranked second on the basis of 6 reviews (score 8.7) while the Ultimaker 2 is ranked 6th on the basis of 142 reviews (score 8.6) (see https://www.3dhubs.com/3d-printers). For this reason, the accuracy of this assessment can be easily questioned; however, it is treated as a legitimate report for actors in the field. The 3D printer guide can be found here https://www.3dhubs.com/best-3d-printer-guide

Figure 14: Marvin Keychain by 3D Hubs (CC A-SA), available from Thingiverse, http://www.thingiverse.com/thing:215703

for their needs, and it does so by leveraging the knowledge of a whole community of 3D printing enthusiasts, enforcing the collective identity of the field.

We would like to argue that these trend reports are anticipatory, in the sense that they provide innovation actors with a sense of prediction; they give a feeling of the momentum of the industry that encourage them to take certain decisions. There reports do not intend to represent the view of a set of experts, but the view of "the community" of 3D printer users. The sense of community and predictability, enabled by social media, has been discussed as "myths" (Couldry, 2014). Second, this practice has effects that can be considered anticipatory coordination: because of the circulation of information about its network 3D Hubs defines relevant categories and sets standards, not only within the network but in the broader 3D printing field. This can be considered a form of infrastructural knowledge, a way of shaping innovation by proactively naming and defining emerging technologies (Pollock & Williams, 2010). While in these reports there are no explicit forecasts, these trends implicitly give an idea of the current momentum the field is going through and what is to be expected. Positive but critical interpretations of these reports are presented in the specialized media or by consultants in the field, who used them to explicitly spot trends. The report also serves to highlight and reinforce the key position of 3D Hubs in the field.

The logic of unlocking a network The two practices we have highlighted in this section, unlocking communities and releasing trend reports, contribute to shaping and fulfilling the vision of 3D printing which 3D Hubs stands for: increase the accessibility of available machines and unlock its technical potential (i.e. increase usage/time) in a decentralized way. This promise is about distributed, local manufacturing accessible to the highest number of people possible, with a potential disruptive effect in society. For this reason, constituting a self-organized network, making this network visible, defining standards and engaging more users are essential steps on the path.

We suggest that the anticipatory practices in which 3D Hubs engages in are characterized by a mixed logic, both open source and techno-economic. While the network of 3D Hubs is co-constructed between the company and its users, the company determines the technical means and definitions over the network. They set standards, mechanism of transactions and the type of publics of the network. Visions and expectations of 3D printing are used as a means to bring the network together, but not necessarily to open its practices. However, each of the local hubs is to a large extent self-organized and instances of recursive and exploratory practice might happen in these local settings.

5.5.3. PrintR and the missing element of 3DP

PrintR is a Dutch company formed in Enschede, the Netherlands who offer an online platform for 3D printing. Their motivation is to bring 3D printing to a wider public by facilitating the process, including design and printing. There have been numerous software solutions introduced to the market to facilitate the printing process (Milkert, 2014). Their solution is composed of a series of products: Formide and FormideOS, the platform itself and the software, and The Element, a "dongle"[85] that promises to make the process of 3D printing much easier and reliable.

This small company, as many others in 3D printing, has gone through a crowdsourcing campaign via the site Kickstarter. A crowdsourcing campaign is an online event where funding is collected for a particular technology. Crowdsourcing can be considered anticipatory because specific expectations about a product are spread in order to create enthusiasm and collect financial resources. This practice has been quite relevant as a means of funding technology startups in early stages in 3D printing, and this is why we consider this particular case in detail. Some of the most successful consumer 3DP companies, such as FormLabs and Zortrax, have been founded via Kickstarter or Indiegogo campaigns. In fact, every week there is a new 3D printer or related product promoted in Kickstarter, and experts (consultants) in the field follow the developments in these websites to get an idea where

85 A dongle is a small piece of hardware that attaches to a computer, TV, or other electronic device in order to enable additional functions such as copy protection, audio, video, games, data, or other services. These services are available only when the dongle is attached.

the field is moving (Interview 6, consultant, 22-10-2014).

The particular crowdsourcing campaign of Printr was organized in the context of a Dutch boot camp for technology startups. This Kickstarter of "The Element" was aimed at covering the production costs of this new product.

"The Element" Kickstarter As explained by one of the members of Printr, the motivation to go for a Kickstarter was the outreach and marketing possibilities such an exercise enables.

> "It was our idea to start the Kickstarter and the reason for that is that with Kickstarter you have a huge reach. Specially for marketing purposes, Kickstarter is way better. Cause if we would have just opened up a preorder system is not really big or you don't get a lot of media coverage or something like that. And if you do a Kickstarter campaign that explains your idea and your product … We got a lot of people worldwide backing us now, and buying our products. So for marketing purposes it is a really good platform" (Interview 10, community manager, 26-02-2015).

A Kickstarter campaign has a standard format. An idea is presented that can be translated into products and those who support the idea – "backers" or financial supporters - receive some benefit (getting it first, a t-shirt, or being part of the dream). As introduction there is a promotional video and a general explanation about what the project is about and its main features. The funding mechanism is based on what backers contribute. There is a list of fixed types of contributions that backers can choose from, which specifies the type of "reward" per contribution. For example, for a contribution of 10 euros you can get a keychain, while in order to obtain the actual product it is necessary to contribute at least 75 euros. There is a timeline that describes the milestones of the project, so the backers know what to expect and when.

There is a Risk and Challenges section, FAQ and the possibility for people to ask questions, add comments or send private messages. In this sense, the Kickstarter page is not static and updates can be made to the project, there is space for interaction with backers and projects get considerable feedback for their products. This is one of the aspects of crowdsourcing that the company Printr considered most interesting but most challenging, because it requires constant attention to the questions raised. In terms of the expectations that are presented in the page, these are rather specific to what the technology has to offer. There are rarely references to grand visions, although "The Element" is presented in the context of the big promise of 3D printing. For example, in the Q&A section, one of the points referred to is if it is open source or not. A member of the company explains why they addressed this topic explicitly.

> It is important because the entire 3DP community exists from open source. So started with RepRap and so people jumped into it and built over it, so almost the entire

> community is open source. I think especially for the really geeky-techy kind of people it is really important to have open source things in it. Also for them to build on top of it." (Interview 10, community manager, 26-02-2015).

Being somehow open source, is in this case a way to refer and relate to a specific "geeky-techy" community and a particular way in which the community organizes through the technology ("they build on top of it"). However, they are not sure which parts would be open source, everything that runs in their servers is proprietary, and that maybe some APIs[86] and the slicer[87] will be open. The open source aspect is still a promise.

The campaign made it into the Kickstarter Staff Pick[88] and it was featured in more than thirty 3DP news sites. However, and because the goal was quite high (100,000 euros) the campaign did not succeed. The campaign was closed with contributions for 44,000 euros[89] and it succeeded in attracting lots of attention from all over the world. This attention was later taken up in a forum and a system of pre-order of "The Element" in the Printr site.[90] Thus, while the crowdsourcing was not accomplished, the marketing effect was the desired one.

Beyond this particular instance, crowdsourcing is a relevant but not uncontested funding model for new 3DP companies. In a recent piece in the site 3DPrintIndustry.com, the author examines the challenges crowdsourcing brings for the industry (Grant, 2014a). By 2014, there were at least 200 3D printing companies that were funded through a Kickstarter campaign (Grant, 2014b). The author argues that this model that in principle is aimed at opening up the process of innovation, can lead to overpromising and exaggeration of the qualities and expectations of a certain product, to which there is no clear accountability.

Among the main criticism to this form of funding is that it raises wrong expectations in relation to product price and functionality, far lower than the market prices. For this reason, projects often do not deliver in time what was promised, but responsibilities for project delay or failure are not often clear (Grant, 2014c). Kickstarter does not take responsibility for the promises, expectations and disappointment that might arise from the projects.

86 An API or Application Programming Interface is a set of routines, protocols and tools for building software applications. APIs work as building blocks for programs other developers can use and build on. For social networking sites, APIs are used to connect between one application and other.

87 A slicer is the program that defines how a 3D design is going to be printed, optimizing the extrusion of plastic, movement of nozzle and other functions required for this task. There are various open source slicers, the most common being the Cura Slicer.

88 Kickstarter's Staff Picks get prime placement on the website and are promoted to the followers of Kickstarter in social media, as well as via Kickstarter email list as "Projects We Love".

89 According to Kickstarter policy, the funding goal is an all-or-nothing, so if the goal is not reached no money is funds are obtained by the Project.

90 https://formide.com/

> The creator is solely responsible for fulfilling the promises made in their project. If they're unable to satisfy the terms of this agreement, they may be subject to legal action by backers (Kickstarter, 2015).

Thus, while the crowdsourcing model appears as a way of opening up the process of sharing expectations and funding a new technology development, it becomes also a space for overpromising which might fuel a hype. This is partly because it has become a marketing tool but also because of the proliferation of crowdfunding campaigns and the lack of accountability of these. We would like to argue that the logic within these sites is less about opening up expectations but rather a techno-economic one. Expectations are presented in terms of their future benefits and gains and at the same time the risks are assessed, and backers are invited to join the project by assessing the financial value of the proposed product. While ideas of "open source" are referred to, they are used for legitimation instead of as a mean to open up the technology.

5.6. Discussion

We have shown that there are a variety of anticipatory practices in which 3D printing actors engage in. All these practices have in common that they refer to a vision of the future of 3D printing, in which the digital is meshed with the material — atoms to data. In this new configuration, anybody can make almost anything, anytime, and as a result there is redistribution of the capacity of manufacturing and ultimately wealth. All these practices speak to an imagined community of makers, users, 3DP enthusiasts or citizens.

We can consider the relation between these expectations and practices a dual one. As we have shown, expectations inform and produce material practices, that we call anticipatory, which at the same time are used to shape these expectations. The anticipatory practices described in this chapter are framed in relation to visions of 3D printing, and they are deployed with the purpose of advancing this vision. The effect of these practices is to further articulate anticipatory processes in the community the actors are embedded in. The specific type of anticipatory effect each practice has varies considerably. For example, in the case of the development of a sharing license by Ultimaker, this practice is deployed in order to concretize a particular vision of 3D printing about the role of the technology in enabling open innovation. This vision is, however, contested by the users' community of the Ultimaker: they do not see the need for the development of a sharing license, and some consider the proposed model of innovation unrealistic. The anticipatory effect of this practice is to open up a space for discussion of different future paths of development of 3DP: one that promotes sharing and open innovation, and one that promotes individual entrepreneurship. In contrast, the specific expectations that are created and mobilized in the Kickstarter campaign of PrintR are successfully spread to a community of users, despite of the failure of the campaign itself. Its effect is on the one hand, increase the attention and expand the network of users of PrintR, but also, increase the attention to the technology in general, potentially contributing to hype – this ultimate effect being anticipatory. The difference in anticipatory effects lies partly in the type of expectations that are mobilized in each case: while the Ultimaker is explicitly normative about the role of 3DP in society, PrintR presents a set of expectations that do not challenge the collective ones, appearing as "neutral". In that sense, it reinforces collective expectations. Thus, the type of expectations that inform and frame a practice will influence to a certain extent its anticipatory effect. This is a recursive process in which material practices and expectations are coproduced.

These practices are shaped by the context in which the technologies develop and at the same time shape this context. They serve as a way to explore and define socio-technical arrangements for 3DP relevant for each of these actors. For example, the way 3D Hubs and the Ultimaker construct their communities relates and translates into a particular way of seeing 3DP embedded in society. In both cases, the aim is to enhance local communities, distributed innovation and empower users. However, how much these communities are engaged actively in technology development differs for each case, and in the case of the Ultimaker there is an explicit aim to allow users to contribute to technology development.

We argue that these differences are partly explained by the different logics that guide these practices. While an open source logic explicitly aims to open up the blackbox of technology and engage users in the development, a techno-economic logic pushes the development of a technology forward by providing a sense of need, urgency and competition. In most practices these two logics coexists and steer the same processes, and what we observe as a result is a combination of both. Similarly, it has been argued that technology development situates between techno-scientific and collective experimentation regimes, allowed by institutions and cultures of innovation that seek to emphasize the importance of distributed innovation by embedding it in existing structures (Felt & Wynne, 2007). What we show is that these two logics, and consequently these two regimes, are to be considered as "ideal types", and that developments in the field move between the two. Actors see these two logics as complementary approaches to technology development in which they need to move about. We see this in the three cases: Ultimaker maintains its open source ethos, while actively using it as a way to gain a central position in the consumer market and "evangelize" the public about the promises and possibilities of 3D printing. 3D Hubs functions based on the strength of their communities, but also in making alliances with industrial players, securing their position in the network. Last, PrintR refers to open source practices as part of a marketing strategy that enables them to enter a particular community.

While our analysis refers to a few actors in the field, we show that there is a large diversity of material practices that more or less explicitly refer to expectations and that these practices are related to central aspects of the operations of each of these companies. Thinking of the larger field, there have been explicit attempts at shaping its expectations such as the development of roadmaps[91], but as we have shown, much of the shaping of expectations happens on the micro level, in material practices in which relevant actors engage. Further research could look at the relation between these micro practices and broader, larger practices aimed explicitly at shaping the field at large.

Last, our account goes beyond an explanation where an open source logic is only seen as a rhetorical means for the 3DP printing movement, but rather we show that this logic effectively contributes to shaping some of the practices these actors engage in. Furthermore, it helps us to understand how open source logics are embedded, adapted and contested in relation to techno-economic ones, and gives some light into the future of innovation processes.

91 For example, there was a roadmap produced in 2009 that was aimed at defining the industry into the future (Bourell, Leu, & Rosen, 2009).

6. How technology consultants assess and deploy the hype

"It is very difficult to predict (the market for graphene) (...). It's very much being a fortuneteller, reading the future via tealeaves or magic at this stage.

But I imagine that you as a consultant don't work as a fortuneteller

(laughs) You'll be surprised..."

[Interview US Technology Consultant, 2013]

Abstract. The hype-cycle is a phenomenon that is recurrently observed and spoken about in the context of emerging technologies. It is characterized by a wave of over-enthusiasm followed by phase of disappointment, in which promises are not met, and later the stabilization and maturity of the technology. A specific type of intermediary actor that has grown in relevance in recent years, known as the technology consultant, plays an important role in assessing, deploying and making the "hype" visible within an innovation community. In this paper I study how technology consultants assess and deploy "the hype" for the case of two emerging technologies: graphene and 3D printing. I describe three different forms in which the hype is assessed: as technical expertise, as a social dynamic, and as social interaction. Each of these forms is a different way of arranging technologies, expectations, and actors, attributing different forms of agency to the innovation process. These three forms of "the hype" coexist as part of the activities of technology consultants and are used in different contexts. There are also practical implications: these different forms allow consultants to maneuver and find a niche for their services in different contexts, while at the same time contributing to the co-production of an emergent field.

6.1. Introduction

New and emerging technologies are often surrounded by promissory claims. These promises and expectations can be considered as a resource used by innovation actors in order to deal with uncertain futures (van Lente et al., 1998). Promises play an important role in the early stages of innovation processes, but can often also lead to exaggerated claims and overpromising. The cycle of exaggerated promises followed by disappointment is known as the "hype-cycle," coined and introduced by the Gartner group consultancy organization (Fenn & Raskino, 2008). This organization provides an annual assessment of how various technologies are positioned in the hype-cycle: either at the peak, where over-promising is high; in the disappointment phase characterized by negative expectations; or in the plateau of productivity, when the technology has evolved and expectations have become more realistic.

This form of "technology assessment" (Swanson, 2010) has spread across various technology fields, becoming a "folk-theory," a shared belief that this trend will repeat itself for every emergent technology (Rip, 2006). In fact, it is often the case that technology actors speak about "the hype" and the "hype-cycle" to refer to different technology and expectation dynamics. In particular, technology consultancies such as Gartner deploy assessments about technological hypes which affect the innovation activities, strategies and dynamics of actors in a technology field (Pollock & Williams, 2010). This paper explores the role of technology consultancy organizations in the assessment and articulation of technological hype cycles. This type of actor seems to take both an enthusiastic and critical stance with respect to a specific technology, a selectively ambivalent attitude that is instrumental in positioning consultants' expertise about a technology. I am interested in understanding how these organizations assess and deploy "the hype" and how this affects the innovation community they are embedded in. I address this question for two technologies that are currently described as "hyped": graphene and 3D printing.

Graphene is a carbon-based nano-material discovered in 2004, which has been creating a strong wave of enthusiasm in the scientific and technological world ever since (Shapira et al., 2012). The promises of graphene have prompted the initiation of a large, publically funded European project – the graphene Flagship – which has aimed at coordinating scientific and technological communities around a shared focal area (Peplow, 2013). These developments have been accompanied by accusations of "hype" from actors ranging from scientists to consultancy organizations (Ghaffarzadeh, 2013; Kozarsky, 2015), who all expressed concern about the negative consequences that overpromising can have for the field.

This is also the case for 3D printing, a novel manufacturing technology that produces objects by adding layers in three dimensions instead of by subtracting material. There are a variety of different technologies that fit the label of 3D printing, distributed between the industrial and the consumer realm. The consumer 3D printer, popularized by the media and some "technology evangelists,"[92] has fueled the hype. Hailed as the enabler of the third industrial revolution by the media and science policy in both Europe and the US, it is expected that 3D printing will radically redistribute manufacturing and innovation capabilities (C. Anderson, 2012). As in the case of graphene, the hype has also led actors

92 A technology evangelist is an expert dedicated to building enthusiasm and a critical mass for a technology. It promotes a particular technology through talks, blogs, demonstrations, books, etc. The term is used to denote activities that popularize technologies in the field, often via exaggerated or blunt claims.

to question the promises around 3D printing and its actual technological potential (Bass, 2013).

In both cases, technology consultants have critically engaged in the production of expectations surrounding these technologies. Their future-oriented assessments range from estimation of potential markets and the benchmarking of products and companies, to evaluations of the state and plausibility of promises and expectations, including the position of technologies in the hype-cycle. The specific consultancy organizations that participate in the production of knowledge about these fields vary between cases. However, despite the differences in the technologies, the ways in which these organizations deploy "the hype" are similar. Against this backdrop, this paper addresses the following research question: *How do technology consultants speak about, assess and deploy the idea of "the hype" and how does it change the innovation field (e.g. what is its performative effect)?* To answer this question I discuss the processes and practices in which the hype is assessed and their effects in the two innovation fields.

This paper is structured as follows: in the following, second part I outline an analytical framework to understand the role of expectations and associated practices in innovation. Subsequently, I explain my research method and approach. In the fourth section I present an analysis of the processes through which graphene and 3D printing consultants deploy the hypes in graphene and 3D printing, and in the very last section I synthesize and discuss my findings.

6.2. Framework: hype-cycles and performative expectations.

Technological hypes are recurrent phenomena, which can be observed for new and emergent technologies. Hypes in general refer to a temporal and spatial evolution of expectations (including promises and concerns) characterized by a peak of high enthusiasm, followed by disappointment (van Lente et al., 2013). This form of characterizing the evolution of emergent technologies has become a shared belief among innovation actors, who speak about, predict and criticize hypes from their various perspectives (Rip, 2006).

The Sociology of Expectations has extensively studied the role of expectations that constitute and lead to hypes in techno-scientific fields. Its main argument has been that these expectations are performative (Brown & Michael, 2003), i.e. they "do something" to the technological fields they refer to (van Lente et al., 1998). Saying that expectations are performative means that they take part in a process in which statements and the worlds they depict are co-produced. In this process, expectations serve different purposes, from legitimation to coordination, from guidance to sense-making (Borup et al., 2006; Swanson & Ramiller, 1997; te Kulve et al., 2013). The production of expectations is enabled and embedded in specific socio-material practices, which have been called "anticipatory practices" (Anderson, 2010). Through these practices the future is made present and actionable through specific materialities such as documents, prototypes, files, presentations, etc., which enable their circulation and performativity (Brown & Michael, 2003). Intermediary organizations such as NGOs, think-tanks and consultants play an important role in the production and circulation of expectations through the production of reports, prototypes, conferences, etc. (Kinsley, 2012; Wilkie & Michael, 2009). Andersson & Rindzeviciute (2015) have shown the historical emergence of specialized “future-experts” and their methodologies such as forecast and foresight. They argue that these methods have become a common way of producing and circulating future-oriented expectations, shaping the way in which technologies are governed.

Pollock & Williams (2010) have argued that in recent years there has been a proliferation of intermediary organizations, commonly known as technology consultancies, that routinely produce future oriented expectations. They call them “promissory organizations” because their core business is the production and circulation of promises and expectations, for which they engage in specific practices through which they coordinate the activities of diverse innovation actors. In their extensive ethnography of the Gartner group, they have shown how this organization has multiple forms of influence, including particular practices such as the production of specific devices to spread out expectations; some examples include graphs for technology benchmarking, rhetoric activities in relation to technology futures, and the production of tentative standards for new technologies. These material forms of expectation enable the deployment and circulation of future-oriented concepts, such as “the hype cycle,” which frame current developments and future possibilities in particular ways.

Studying the construction of the concept of “future users,” Wilkie & Michael (2009) have asked how it shapes the type of expectations and futures that are made possible for an emerging technology. They have shown how the specific forms in which this concept is deployed enable and constrain the policy process in the articulation of 3G mobile technologies. Future users are portrayed as agents with the ability to shape a technology, but at the same time are presented as an entity that emerges from heterogeneous relations, practices, devices, people, information, and the technology itself. Thus, there are different definitions of future users that co-exist and that co-produce those very users. Law & Mol (2002) have drawn attention to knowledge practices of definition and simplification, in which complex phenomena are translated into simple models. They argue that there are different ways of ordering and structuring things, and that these different simplifications co-exist with their own forms of organizing the world. Similarly, “future users” are co-constituted and performed together with 3G technologies, and the way in which they are defined produces different “future users” as assemblages of technologies, actors, practices, regulations, etc. This in turn is instrumental in bringing about different policy options and different kinds of technologies.

Thinking along those lines, it is interesting to reflect on the way in which consultants working with new and emerging technologies deploy the idea of "the hype" when they speak about the promises of a technology and its development. In fact, they do not only mention "hypes" but they actually assess the hype through various methodologies and practices. For instance, the Gartner group positions a technology in the hype cycle based on a consensus assessment of many analysist about the state of expectations, the maturity of the technology, business applications, and industry. Each of these assessments is based on "proprietary" methodologies that can include econometric analysis, interviews, participation of events, etc. Thus, it is worth asking how the ways in which the hype is assessed and deployed influence the development of an innovation field. Specifically, when "the hype-cycle" is referred to, it is presented as a simplified version of the dynamics that occur between expectations and technology development. Each of these simplifications is a form of representing relations between the social and the technological, providing them with different forms of agency (Law & Mol, 2002; Wilkie & Michael, 2009).

To begin with, it is necessary to define what I understand by hype, since the word "hype" has multiple meanings, and the phenomenon of "hype-cycles" has multiple dimensions. Multiple understandings of hype can be found in the literature (2). Hype can be understood as the act of hyping: exaggerating or overpromising by technology actors, used strategically to gain support for a new technology (Ramiller, 2006; Ruef & Markard, 2010). Hype cycles can also be considered as a media phenomenon in its own right. It then denotes a phase of strong media attention that is followed by disappointment, which again might have longer-term negative effects for the perception of a technology by different groups of actors (Jensen, 2012; Master & Resnik, 2013). The "hype" is also used as an assessment tool of the market for a certain technology, as it has been implemented by the Gartner group and other consultancy organizations (Fenn & Raskino, 2008). Consultants have popularized the figure of a technological hype for new technologies to the point that it has become a shared belief among innovation actors (Rip, 2006). Borup et al. (2006) argue that "the hyperbolic character" of expectations is characteristic of the knowledge society, in which research is often valued by its impact on industry and other areas. Along these lines, hypes can also be understood as "social bubbles" (Gisler et al., 2011), i.e. as a wave of strong social interactions in new ventures that lead to reinforcing feedback and extraordinary commitment of those involved in these ventures, connecting seemingly incompatible interests of scientific actors with those of the private sector.

Social scientific approaches to understanding hypes are informed by some of these definitions, either describing strategic activities of actors in relation to hype (Nerlich, 2013; Ramiller, 2006; Vasterman, 2005) or the discursive dynamics of expectations (Bakker & Budde, 2012; Hyun Kim, 2012; Ruef & Markard, 2010; van Lente et al., 2013). In this paper, I focus instead on the forms in which hypes are assessed and deployed as part of the practices

Table 2: Different definitions of hype

Type	**Definition of hype**
(1) Hype as exaggeration	Hype or exaggeration is a practice by which technology actors more or less strategically raise and circulate exaggerated claims in order to promote a technology, in which the positive is highlighted while negative aspects are downplayed (Caulfield & Condit, 2012; Ramiller, 2006; Rinaldi, 2012; Ruef & Markard, 2010).
(2) Hype as increased media attention	Hype as a wave of media attention that is characterized by very optimistic and exaggerated expectations, followed by more modest or negative expectations, which again create negative longer-term effects for the public trust in a given technology. These expectations are found mostly in media sources (Jensen, 2012; Master & Resnik, 2013; Ruef & Markard, 2010; van Lente et al., 2013).
(3) Hype-cycle as an assessment tool	The figure of the hype cycle refers to a particular way of assessing the status of an emerging technology given the expectations that are raised about it and its technological maturity. (Fenn & Raskino, 2008; Pollock & Williams, 2010).
(4) Hype as a folk theory	A belief in the hype-cycle as a recurrent phenomenon for new technologies, which actors recognize and expect to occur, and use to draw conclusions without being an object of systematic research (Brown & Michael, 2003; Rip, 2006).
(5) Hype as a social phenomenon	Hype as a wave of enthusiasm that mobilizes innovation actors to take risks that they otherwise would not take. It plays an important role in creating and sustaining protected spaces for new technologies (Borup et al., 2006; Gisler et al., 2011; Ruef & Markard, 2010; van Lente et al., 2013).

that technology consultants engage in when working with emergent technologies. How are hypes identified, assessed and spread in the public discourse, and what are the performative effects of such actions? In this respect, "the hype" is the result of expectations, actors, technologies, innovation activities and other elements that are assembled in various ways.

6.3. Research Approach & Methods

This paper is based on two in-depth case studies in two distinctive emerging technology fields: graphene and 3D printing. For both cases, I followed and studied the activities of a set of promissory actors. The selection of actors was not predetermined from the beginning, but was the result of the evolving field work: the consultancies referred to here are the organizations and actors that were encountered during each case study and appeared to be relevant in the field according to the interviews.[93] It is important to note that these actors do not represent the overall universe of promissory organizations in each field.[94] Rather, what are presented here are vignettes that give insight into the process of assessing hypes.

The data collection included semi structured interviews with consultants in the graphene field (3), consultants in 3DP (2), as well as technology bloggers (2). Some of these actors were interviewed several times. The interviews were complemented with field notes from two 3D printing events (Euromold[95] (DE) and 3D Printing Event[96] (NL)) and three graphene events (Graphene 2013[97] (ES), Graphene Stakeholders Association (GSA) Meeting[98] (US) INC9[99] (DE)), in which some of these consultancy organizations participated either as organizers, with a stand, or as speakers. This data was complemented with an analysis of the websites, blogs and social media (Twitter and LinkedIn accounts and groups) of the consultants.

In the empirical description of the case, I refer to several types of actors, from company CEOs to consultants themselves. For this reason I will start by clarifying the differences

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93 I asked in interviews with other actors in the two fields about consultants they had contact with, those they considered more trustworthy, and why. This set of questions led to a reduced number of organizations compared to the total of consultants in the field, which are the ones referred to here.

94 It is important to note that some of the consultants referred to here are well known in each field. What I want to stress is that this is neither an extensive study of one organization, nor a comprehensive study of promissory work in a field.

95 http://euromold2015.com/en/

96 http://www.3dprintingevent.com/

97 http://www.imaginenano.com/SCIENCE/Scienceconferences_Graphene2013.php

98 http://www.graphenestakeholders.org/gsa-events/

99 http://www.inc9.de/index.php?id=home

between the different types of actors. "Consultant" refers to a member of established organizations such as Gartner or other technology consultancies. "Independent consultant" refers to individuals who do not work officially in an established organization but offer their services as experts in a certain technology field independently. Lastly, "technology media" refers to actors who are involved in the production of information on diverse media (incl. social media, blogs, online videos, forums, etc.) about a particular technology, and who may or may not be associated to a consultancy organization. As I will show in this paper, all these actors are interrelated in the process of sense-making of hypes.

The guiding heuristic for my data analysis was to identify the instances and ways in which consultants made references to hype. This included not only consultants themselves, but also how other actors referred to the way in which consultants framed hypes. I coded the data in such a way as to distinguish specific ways in which the hype was deployed and the type of anticipatory practices involved. In particular, I paid attention to how these practices were produced by various promissory actors and the type of relations that these practices entail. Lastly, I considered the relation between different forms of deploying the hype and their performative effect in relation to the co-production of the broader technological field.

6.4. Consultants assessing hypes

In this section I analyze three ways in which consultants assess and deploy the hype, and the way in which each of these interpretations of the hype assembles different elements of an emergent field.

6.4.1. Assessing hypes by technical expertise

A characteristic feature of new and emergent technologies is that there are accusations of hype during a phase of high optimism and attention (Kitzinger, 2008; Ruef & Markard, 2010). Different actors (scientists, entrepreneurs, etc.) will claim that "technology X is hyped" (often referring to media framings) and strategically act upon this claim (Budde, Alkemade, & Weber, 2012; Konrad et al., 2012). I argue that to position these claims, hypes also need to be assessed as such, and this is largely – but not solely – the work of promissory organizations. This means that a consultancy organization will make a diagnosis of expectations related to a technology and assess if these expectations are realistic or exaggerated, based on their technical expertise about a technology. This assessment is often presented as part of the results of a broader analysis of a specific technology, such as an analysis of its potential market, presented as a market report. The potential market of a technology is estimated through methods that include interviews, benchmarking, trend analysis and forecast. This is often accompanied by press releases that refer to the hype status of a technology. These hype assessments are used as part of the general information and promotional media that is circulated to promote reports.

I will illustrate this type of assessment with the case of 3D printing, in particular how the Gartner group has been reporting about the 3D printing hype. These reports play an important role in articulating the idea of a technological hype. The Gartner group yearly produces hype-cycle assessments for emerging technologies which feature "technologies that are the focus of attention because of particularly high levels of hype," or those that Gartner believes have the potential for "significant impact," enabling organizations to identify new business models (Gartner, 2014). When a technology is introduced to this hype-cycle, it gains visibility and becomes a subject of discussion, and technology actors, including company CEOs and technology developers but also scientists and policy makers, use this assessment in their own decision making processes (Steinert & Leifer, 2010).

Since 2010, the Gartner group has been mentioning 3D printing in this hype-cycle assessment (Gartner, 2010). A feature of the hype-cycle as a methodology for benchmarking emerging technologies is that technologies are supposed to move through different stages of the hype over time: from the peak into the disappointment trough, and then towards a plateau of productivity (Fenn & Raskino, 2008). From 2010 to 2012, 3D printing was presented as a single technology located at the peak of the hype (Figure 15). In fact, media attention towards 3D printing is such that it has not decreased over recent years, but rather increased. This means that in terms of the cycle, the technology has remained at the "peak of the hype" for about 4 years; yet, this does not mean that its expectations remained unchanged. The promises of 3D printing have shifted from general ideas and hopes about the potential of the technology, to a more structured discourse about the specific possibilities of the technology in different areas of application. In this process, innovation actors have made clear the different affordances of each technological path and its future possibilities (Potstada et al., in press).

In 2013 the Gartner group changed its assessment of 3D printing to speak of not one, but four different technologies, located at different points of the hype: 3D bioprinting, enterprise 3D printing, consumer 3D printing and 3D scanning (Figure 16). In this new assessment, consumer 3D printing still remained at the peak of the hype, while the other technologies were well spread over the cycle, either in the beginning or the end. As explained by an independent technology consultant who is not related to Gartner,

> Gartner started to distinguish between consumer 3D printing and enterprise 3D printers last year (2013) which I think is really helpful. The big advances and developments, and the really meaningful stuff in the short term will come from these enterprise applications. Now regarding consumer 3D printers, it's really funny how consumer 3D printing sort of got stuck on the maximum point of hype, peak of inflated expectations. And you know this in itself creates a lot of probably very short-term opportunities. (...) So there is this kind of self-fulfilling prophecy of that hype

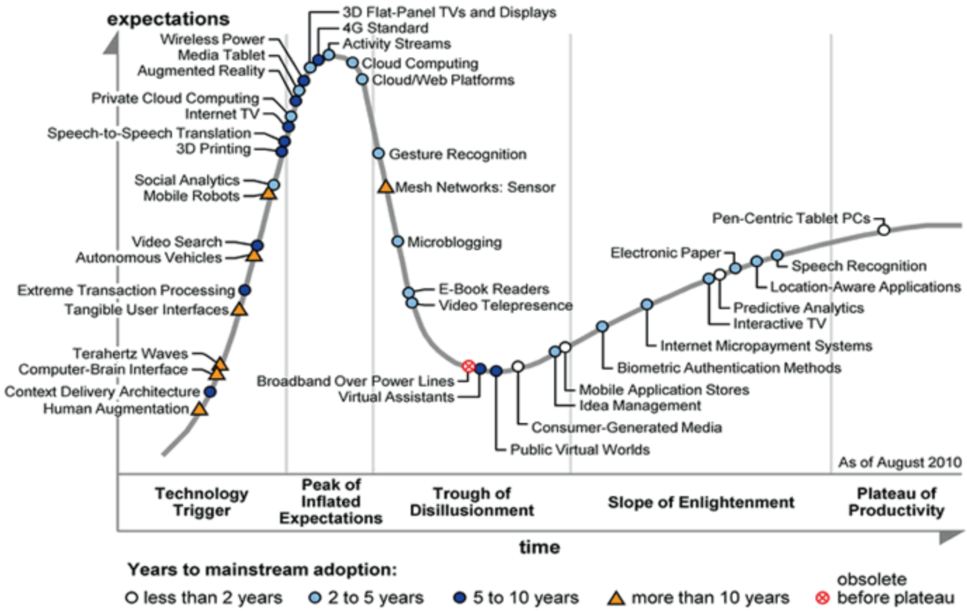

Figure 15: The Gartner's Hype Cycle for Emerging Technologies 2010. 3D printing as a single technology is located at the beginning of the hype, in the Technology Trigger phase. Non-modified version, used with authorization of Gartner Inc.

> which I think is really sort of short term. But if we look at the facts (it) has been around for the last, say, 4 to 5 years... which is kind of amazing. And it keeps repeating itself, it doesn't move, there is very little progress to be seen. (Interview 8 3D printing, independent consultant, October 2014)

This new assessment, as explained by an independent consultant, provided in his opinion a frame that was closer to the observed dynamics of the field: enterprise 3D printing advanced in terms of concrete new business models and application areas, while consumer 3D printing remained at the peak of the hype without a clear "killer application." This perception was shared by other consultants. As he notes, keeping consumer 3D printing at the peak of the hype, while distinguishing it from other 3D printing technologies, is not only the reflection of strong, ongoing media and public attention, but also creates a "short-term self-fulfilling prophecy." In this new assessment of the hype, different technologies under the label of 3D printing are positioned against their general and specific promises, structuring what becomes the most "reasonable" paths of action. This means that a "window of opportunity" is created for the technology at the peak, which is characterized by high expectations that enable the emergence of new consumer 3D printing companies. This

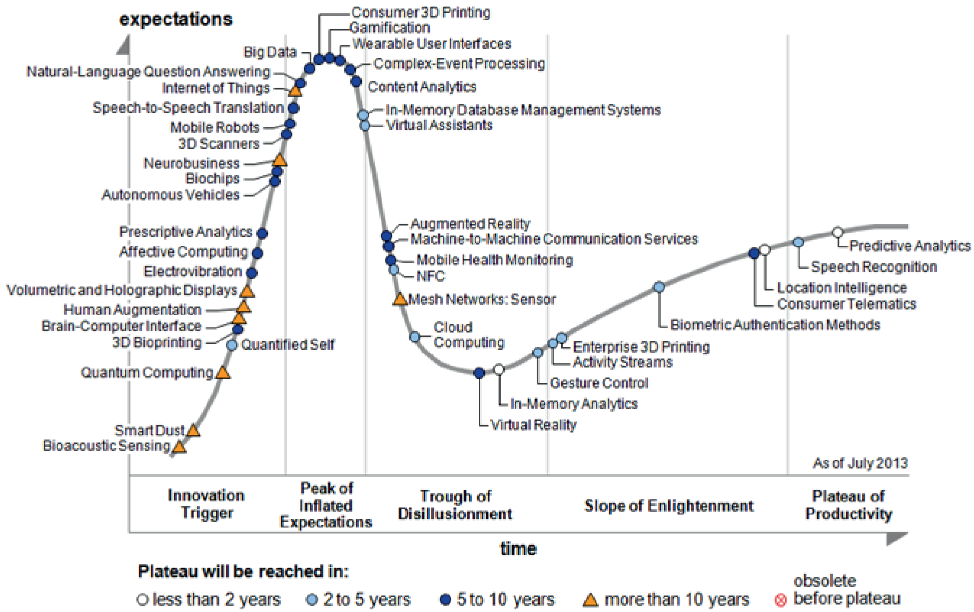

Figure 16: The Gartner's Hype Cycle for Emerging Technologies 2013. 3D printing is presented as four different technologies: 3D Bioprinting and 3D Scanners in the Innovation Trigger phase, Consumer 3D Printing at the peak of the hype and Enterprise 3D printing moving through the hype into the Slope of Enlightenment. Non-modified version, used with authorization of Gartner Inc.

again reinforces and keeps the expectations about the technology high. That is to say, this self-fulfilling prophecy is co-produced and reproduced as the assembling of technologies and expectations in a reinforcing cycle. Being at the peak of the hype means that the particular arrangement of expectations, technologies and actors creates momentum for investment, and as this consultant notes, it becomes a self-reinforcing cycle.

This example illustrates how the hype cycle is not a just a method for prediction — its function is not to forecast technology dynamics. Instead, it is what Pollock & Williams (2010) call a critical tool, a way of organizing the field. Based on their expertise, different analysts with technical knowledge in a specific area will assess the maturity of the technology, its market value and its business prospect. Such assessment is a combination of defined methodologies and the "expert view" of a field (Pollock & Williams, 2010). In the case of 3D printing, Gartner employs a particular method of assembling expectations that opens or closes "windows of opportunity" for innovation actors.

6.4.2. Assessing hypes by social dynamics

A second way in which hypes are deployed is presented as the result of social dynamics between innovation actors. This form of assessing hypes departs from the "technology maturity versus expectations" framework that represents the Gartner group's hype-cycle to reflect on how different groups of actors engage in the production of expectations about a technology. These assessments are circulated either as part of market reports, in blogs and press releases, or discussed in technology events. I will show that these assessments deploy different understandings of the hype on graphene by two consultancies. The first one is the assessment provided by the printed electronics consultancy IDTechEx that explains how the hype-cycle develops (Figure 17), and the second is the way in which the former nanotechnology consultancy Cientifica refers to what they call a nanomaterials hype cycle.

The company IDTechEx was founded in 1999 and is specialized in printed electronics and related areas. It is composed of a set of analysts dedicated to different emergent technological fields. They entered the graphene field in 2011 when they released a report in which they compared carbon nanotubes and graphene (Das, 2011). This release was driven by the interest that clients of this company expressed in graphene (Interview 14 graphene, consultancy organization, July 2013). A recent graduate from UCL, holding a PhD in electrical engineering, was hired by IDTechEx at the end of 2011 to take over graphene and related applications topics. Quickly he became an authoritative figure in the field (Interview 8 graphene, company CEO, December 2013 and Interview 10 graphene, technology blogger, June 2013).[100]

Their assessment, shown during a series of conference presentations, press releases, webinars and in their blog, diagnosed that graphene was moving just past the peak of the hype. A press release of 2012, which accompanied the release of a market report, included a figure of the graphene hype (Figure 17). This figure, which is referred to as the hype-cycle for graphene, represents the different stages of the hype in a way that is clearly informed by the framework provided by Gartner. The assessment provided at this point was that graphene was moving past the peak of the hype, based on indications such as companies going through a second or third round of funding, more realistic assessments of markets, and more "calibrated" expectations being circulated in the media (IDTechEx, 2012).

While this framework is closely related to the Gartner hype-cycle, there is an important difference in the way it is used. What differs in IDTechEx's assessment is that they identify a spread of graphene activity, which means that graphene is not located at one point of the hype but at various points simultaneously, depending on the type of actor and technology they are referring to. This positioning is not solely based on a comparison between expectations and reality, but also on the activities these companies are engaging in, particularly their relation to financial actors and development of markets. For example,

100 The success of this analyst is such that he is now the Head of Consulting at this company.

it is implied that a second round of funding is a sign of maturity of the technology. The graphene hype-cycle is portrayed as the result of activities of diverse innovation actors, most importantly financial and technology actors, which change their relation over time as indicated by the activities they perform. This framework therefore draws attention to the way in which actors interact with others, rather than the technology itself. IDTechEx's framing of the hype makes explicit the relations between actors, and directly targets the activities of investors. This hype assessment is explicit about the relations that are being developed between financial actors and emergent companies, and how this affects the development of a graphene market.

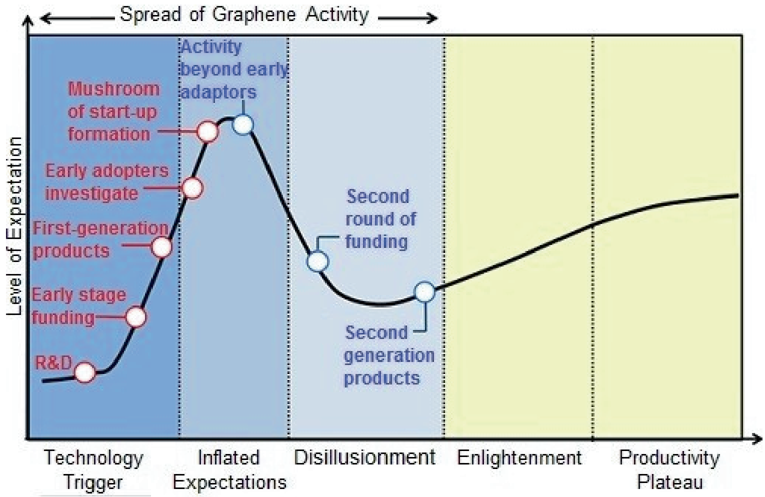

Figure 17: The IDTechEx Graphene Hype Curve, as presented in their 2013's report. Source: https://www.cambridgenetwork.co.uk/news/idtechex-forecasts-a-100-million-graphene-market-in-2018/ (reproduced with permission from IDTechEx Research)

A different assessment of the graphene hype was provided by another UK based organization, Cientifica. Founded by Tim Harper, a charismatic figure in the nanotechnology world, the organization bears its founder's name in many of the activities it engages in. He is in fact the most visible figure of this organization. He has been involved regularly in promissory activities such as workshops, conferences, release of reports, and has served as consultant for a wide range of organizations, including the World Economic Forum.

In June 2013, this company released a report called "Investing in Graphene" that provided an assessment of the emergent graphene market (Cientifica, 2013). This market report was in many ways similar to the other ones that were released at the same time by other consultancies: it included an assessment of the graphene market, and benchmarking of companies, applications, and future prospects. It was accompanied by a press release and a short summary of the report that included a historical overview of carbon materials and its implications for graphene. Most importantly, the report introduced a framework to understand what was referred to as "the nanomaterials hype-cycle." This cycle is characterized as a wave of overenthusiasm that moves through different actors groups. The main "selling point" of the report is a guide to "navigate" the cycle. The cycle is composed of five phases: (i) the academic hype, (ii) the corporate hype, (iii) the financial hype, (iv) the bubble burst and (v) the morass. This hype-cycle is described in a one-page explanation, where all the "hype expertise" of Harper and its organization is displayed. Particularly interesting is his assessment of the peak of the hype, stage (iii) or the financial hype.

> "At the peak of the cycle with public awareness building, a range of investment gurus exchange traded funds and brokerages scramble to get a slice of the pie. Technology experts and investors emerge from every nook and cranny, and every week at a conference someone predicts an even bigger market. A few companies (and their investors) get rich from well-timed IPOs. Companies engage in a production capacity arms race in order to address a still non-existent market." (Cientifica, 2013)

This description is in line with earlier assessments, and also with IDTechEx assessment, that show that hypes and financial markets are intimately related (Gisler et al., 2011; Wüstenhagen et al., 2009). Particularly because during times of hype there is more availability of investor funds and venture capital that make it easier for newcomers to enter a field (Interview 8 graphene, company CEO, December 2013 and Interview 27 graphene, company CEO, December 2013). As if it were a self-fulfilling prophecy, shortly after the release of this report Cientifica announced that it would transform its operations from a consultancy organization to an investment one. In the second half of 2013, Cientifica PLC went public into the AIM market of the London Stock Exchange.[101] The area of investment of this renewed Cientifica was mainly graphene.

This was not the only company that went public under similar conditions at the end of 2013: at least two other UK based companies, producers of graphene, did the same. The overall response of investors was very positive, with the IPO being even "oversubscribed." The hype went, however, far beyond the mere oversubscription. At the very end of 2013 (30.12.2013) the financial authority of the UK (Financial Conduct Authority, FCA[102]) warned that investments in graphene were dubious due to the lack of standards and regulations in graphene, and it could not confirm the quality of products. As the FCA put it, "*we are concerned about investments involving a man-made material called graphene. Find out more and how to protect yourself.*" This particular incident coincided with the earlier assessment of the hype provided by Cientifica: the financial hype, in which financial actors take advantage of

101 Cientifica did not technically engage in an IPO but took over an existing company in the AIM market, namely Avia Health Informatics.

102 http://www.fca.org.uk/news/graphene

the expectations about a technology and make strategic investments.[103] This second form of assessing and deploying the hype gives a structure to the way in which various types of actors become engaged in graphene and shape the graphene hype. It defines the way in which actors raise expectations and the way they are assembled. In that respect, the hype becomes the result of the way in which actors align in relation to expectations and to each other. This is clear from the way Cientifica assesses, materially circulates, and performs the peak of the hype.

These two forms of assessing the hype deploy it and represent it as a social dynamic. In that sense, the hype is not portrayed as the juxtaposition of a technology versus its promises, but rather as the way in which innovation actors relate to each other. This representation of the hype assembles actors and the particular practices they engage in, related to expectations, in an orchestrated manner, in which a scientific discovery is followed by the development of technological products, investment, and the public uptake of these technologies. It defines the kinds of relations that can take place between different kinds of actors and how they are expected to behave. However, the way these "social" assessments are presented differs. IDTechEx's interpretation of the hype takes distance from the dynamics it represents, appearing as objective, based on "facts" and as a form of abstract knowledge that can be used by any other actor in the field (Suddaby & Greenwood, 2001). In their representation of the hype, there are no particularities of the technology itself, but instead a given structure under which companies, investors and technology developers and their expectations relate to each other.

In contrast, the hype assessment provided by Cientifica puts this organization at the core of the hype itself. It is largely based on their own experience in the nanotechnology field and in particular with carbon nanotubes, and on the expertise they have acquired from it. It does not intend to be generalizable to every technology; instead, showing the particularities of nanomaterials, it aims to position Cientifica as relevant experts in the field, who can be trusted when it comes to nanomaterials investments. There is a difference in the way "investment" is treated in these frameworks. For IDTechEx, a first and second round of investments are signs of positive expectations and maturity; in contrast, for Cientifica, a round of investment is inevitably accompanied by a "bubble-like" effect, in which expectations are not met. These different assessments also reflect the way each consultancy positions itself among other actors in the field: IDTechEx presents itself as an objective observer of the dynamics, while Cientifica is explicit about their ability to shape

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103 In Harper's hype-cycle this would be followed by disappointment, or the stage he calls "the bubble burst.. However, disappointment – at large scale – did not materialize despite the fears raised by the FCA. The attention to graphene had diminished, but not at the expense of disappointment, due to coordination activities developed by actors in the field to avoid negative expectations. Thus, the predicted bubble burst for graphene has not yet materialized, although there are some early indications of disappointment (Kozarsky, 2015; Peplow, 2013).

the field itself.

These two assessments move between two different ways in which consultancies define their roles in a field: either based on their expertise and ability to technically assess a particular topic (and this is why they need frameworks), or, on the other hand, based on their experiential knowledge. These actors "know hypes" because they have experienced it a number of times (Interview 10 graphene, technology blogger, June 2013). Thus, they have the experience to guide other innovation actors through the hype in a way in which they can avoid its downsides and negative effects.

6.4.3. Assessing hypes as a form of social interaction

Finally, I show a third form of assessing hypes in which the hype becomes a space in which to collectively frame expectations about a technology. This third form of assessing the hype is constituted by the collective disassembling and reassembling of expectations, frameworks, and assumptions about a technology, which happens through the interaction of consultants with other innovation actors during particular events. In this case, the notion of hype is presented as related to the plausibility of the expectations that circulate around a technology in a certain time. The accuracy of expectations can only be fully assessed in retrospect, thus whatever is assessed as a plausible expectation must be understood under a set of criteria that lie outside its correspondence to actual facts.

As Pollock & Williams (2015) have argued, the site of predictions has moved from the text (the literary) to interactive events, where predictions that promissory organizations make are socially checked. In these events, assessing the robustness and credibility of expectations is a largely interactional process in which predictions are socially evaluated. It is particularly in the interactive setting offered by technology conferences that a meaningful exchange between innovation actors and consultants can take place.

Technology events (often called conferences, trade fairs, summits, etc.) are present both in graphene and in 3D printing. While in graphene, market-oriented events have only started to take place in recent years (the first ones in 2012), for 3D printing these events are already a common part of technology fairs, which are a regular practice for the manufacturing industry.[104] These events are often run by specialized organizations, which I refer as technology media.[105] Consultancies also organize events in specific areas: IDTechEx

104 Rapid Prototyping, which is the basis of 3D printing, has been for many years discussed and presented in industry fairs such as Euromold, one of the largest fairs for moulding and tooling for the manufacturing industry. I attended the 2014 edition of this fair that took place in Frankfurt, which featured a large exhibition of 3D printing companies and machines.

105 These companies put considerable effort into creating and sustaining a public for their events. While doing fieldwork, because of my presence in social media I was contacted by various companies (via email, phone, or letter) to see if I was interested in attending their events. It is important to note that often in addition to the presentations and stands, there are workshops, brokering events, and other activities. The

co-locates an event called Graphene LIVE! with their Printed Electronics show, and they also organize an event about 3D printing. During the year many of these events will take place around the world, and for technology companies it is important to be present either with a stand or as speaker in as many events as possible (as seen in some of the events attended such as GSA meeting 2013 and Euromold 2014).

In these events, the hype is assessed and deployed collectively; expectations are discussed, analyzed and assessed in a process led by consultants. This was the case of a graphene conference in 2013. In this conference, a consultant from IDTechEx was invited to speak about graphene and its future. He diagnosed a hype about graphene, attributed to a "market confusion," which derives from the fact that "graphene" refers to a multiplicity of materials of different qualities and fabrication methods, and which can be used for very different applications. As he explains,

> "We all know that graphene is a great material, it is probably the best material ever created, but when you look at it from the market point there is no one type of graphene, there are many types, and each represents a different market." (IDTechEx consultant, Graphene 2013 Conference)

By introducing this distinction, he offers a different way of thinking about the graphene hype: it is not only the result of exaggerated expectations, but also the result of a lack of coherent narrative about what the field is actually about, its interconnections, and the product structure. He also offers a new way of thinking about what graphene actually is: instead of a singular graphene, there are multiple "graphenes," different materials with distinctive properties. Each of these different "graphenes" addresses a different product space (i.e. they refer to different expectations), so different strategies need to be developed for each case. The consultant engages in a type of benchmarking exercise where he compares the advantages offered by each form of graphene against the materials it intends to replace for different applications.[106] He shows that the lack of a coherent narrative of what graphene can do is counterproductive to setting up a market. Or, as he argues, "*being a little bit cheaper and being a little bit better won't create a market for graphene.*" In this fragmented space, coordination among different market actors (producers, consumers, users and investors) is hard to achieve and there is space for misunderstanding. Coordination is necessary to produce a real market for graphene, which would essentially be enabled by a game-changing or "killer" application[107] that takes graphene into the mainstream.

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price for a ticket to such event is not less than 300 euros on average.

106 For example, graphene has been postulated to be a material to replace ITO, the main component of touch screens. This type of graphene is different than, for example, graphene used for batteries.

107 A killer application is a product that has such highly desirable properties that it generates high profit in a short amount of time. It also helps to promote the underlying technology, helping to provide disruptive technologies with wide societal acceptance (Becker, 2009).

The audience of this talk, mostly scientists, received this critical claim with some surprise. However, as my participant observation suggests, this did not undermine the legitimacy of these claims or the knowledge it entails. Instead, it gave the analyst authority and credibility among other innovation actors. This is a common trait of the consultants in graphene and 3D printing: they are both critical and optimistic. They tend to present themselves as critical observers of the dynamics of the field who provide frameworks to understand, evaluate and act in relation to the developments in each field. By doing so, they generate legitimacy for their hype-cycle assessments, for the field, and, ultimately, for themselves.

A similar instance of problematizing expectations takes place in 3D printing events. In a conference organized by the technology media company TCTShow in 2014, there was a set of presentations called "Debugging 3D printing." In these talks the presenter would ask the audience to distinguish truth from exaggeration in the field, by providing the means to assess claims, promises and predictions. One of the speakers performed a game-like exercise in which the audience had to decide if a certain statement on 3D printing was plausible or not, by lacing it in one of two rows, labeled "ridiculous" or "plausible" (TCT+Personalize, 2013). The speaker introduced this game by saying that there are a lot of myths and misinformation about 3D printing, for which he blamed the media. Instead, he noted that he was committed to finding those expectations that are real, and looked for legitimation in the audience, especially among those "who work for the industry." The first myth he "debugs" is: can you 3D print anything?

> I am gonna start with "you can 3D print anything." Common misconception; 3D printing has a lot of rules and regulations to it, and you can't… on a lot of machines you can't print certain complexities. One of the tricks of 3D printing is that you can print any shape but actually on some of the FDA machines you can't print overhangs unless they have the support material or you built a support structure into it. Anyone got an opinion on this?... this is all completely unfair! I need someone at least! … that it's ridiculous! can you 3D print anything? No, OK. So, a vote on this? Can you 3D print anything? This way? Ridiculous, plausible, ridiculous, plausible… Hands up for ridiculous? Hands up for plausible? Yes! One nailed (TCT+Personalize, 2013)

By engaging in this myth-busting exercise, he not only mobilizes technical knowledge to argue against the "myth," but also puts into question his own assumptions and looks for support from the audience, who has the tacit and experiential expertise to assess these predictions. To do so, he raises these and other propositions that circulate in the media about 3D printing (3D printing will bring jobs back to the West, 3D printing is good for the environment, etc.) and presents his own way of thinking about it. He allows the audience to respond to these propositions, explaining why they think a prediction is accurate or not, and to decide whether a prediction is ridiculous or plausible. By means of this exercise, he tries to show that the frames of thinking about technology that lead to hype are simplifications of complex problems. For example, as he goes on to discuss the question: is 3D printing cheap?

> Now cheap is a difficult one to discuss cause cheap can be… if you have a 3D printer at home, is it cheap to buy a spool and print a plastic item. Or is it cheap to manufacture a good by 3D printing. (…) 3D printing is cheap when it comes to low value manufacturing, (…) but there is no economy of scale with it. (TCT+Personalize, 2013)

The discussion is opened to the floor, which, based on their own experiences with 3D printing in the medical, aeronautical or jewelry areas,[108] audience members present their different perspectives, showing that 3D printing can be cheap in certain cases. For this reason, the speaker decides to divide his slide in two and put half of the statement in the ridiculous part of the board and half in plausible. The process is not just a consultant showing his expertise, but a form of dialogue in which knowledge is created in a distributed way. Actors themselves, including consultants, "learn" from the experience of other technology actors and undergo a transformation. In fact, for technology consultants it does not seem to be delegitimizing to be proven wrong, or to change their opinion about a subject (Pollock & Williams, 2015; Reeves, 2014). In this sense, their knowledge about a field is accepted as highly contingent.

This third form of assessing and representing hypes is its foremost collective. It involves the collective disassembling and assembling of the expectations that make "the hype" by actors who are themselves participants in the hype. This is possible in collective practices such as technology events, in which an informal dialogue emerges between consultants and other innovation actors. Expectations are discussed, opened up, reframed, and not just proven wrong. Re-framing expectations and the way of thinking about the field creates space for multiple interpretations and predictions: graphene will be different depending on the type of material we are speaking about; 3D printing can or cannot be cheap, depending on how an application is benchmarked against its competitors.

By reframing generalized expectations into complex narratives, multiple possible paths become evident. One might ask what the use of such rephrasing is. The way in which consultancies make profit is mostly by providing one-to-one services to companies or investors (interview 14, consultant, 18/07/2013). By opening up such multiple opportunities they expand the market; at the same time, they make expectation look less "unrealistic" and more "imprecise," triggering the activities of other innovation actors to explore these multiple possibilities.

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108 Jewellery, aeronautic and medical prosthesis are the three areas where currently 3D printing is developing faster and with more concrete applications. Particularly in these areas, the comparative advantages of the technology are clear.

6.5. Discussion: The materiality of hypes

This paper discusses three forms of assessing, deploying and representing "the hype" by technology consultants, which are different forms of representing how expectations influence the strategies of actors and the development of technologies. These three forms are *technical expertise*, *social dynamic* and *social interaction*, and they refer to characteristic ways in which technology consultants define, assess and make hype-related claims. These different assessments are all produced by the same technology consultants, but deployed in different contexts and different practices.

An assessment based on *technical expertise* represents hypes as a relation between technologies and expectations, in which a technology is in an early stage and needs maturity to achieve its promises. In this type of assessment, actors are absent from the production of a hype. The potential of the technology is there, and the peak of the hype appears as an opportunity. This representation of the hype emerges from the technical expertise consultants have about a technology, taking some distance from the dynamics of the field itself. To do so, they rely on a specific device: the Gartner hype cycle, in which technologies are positioned and benchmarked against each other based on market situation, technology maturity, IP and other variables.

An assessment of the hype as a *social dynamic* represents it as the result of relations between different types of innovation actors that change over time. In this way, what actors can expect from others is orchestrated by the frame given in reports, social media and technology events. This assessment is presented as the result of the experiential knowledge consultants have in the field, i.e. actors who know about this early stage dynamic because they have experienced it a number of times. In this second form of assessment, the expertise of consultants is predicated on the position they have among other innovation actors, as an abstraction of the social network in which they operate (Evans, 2007).

Lastly, an assessment as a form of *social interaction* interprets the hype as a space in which to question the expectations about a technology, such that the underlying conceptual assumptions are collectively opened up and reframed. This last form of assessment takes place in technology events, which are the "site of prediction" of technology consultants. As has been argued (Pollock & Williams, 2015), the function of these consultants is not primarily to make accurate predictions. Rather, they provide a framing that allows other technology actors to speak a common language and that guides their collective action. In fact, it does not matter if the predictions made by consultants do not materialize, or if they change opinions over time. By collectively opening up "the hype," and reconstructing what counts as plausible expectations, consultants are also able to position their own expectations and, most importantly, expertise, in the field.

As I have shown, the same organizations produce different assessments of the hype, which distribute agency among technologies, expectations and actors in different ways. A technical assessment of the hype understands the innovation process as the result of technology itself; a social dynamic assessment gives a limited agency to actors, setting the boundaries under which they can operate. A social dynamic form of hype gives higher agency to actors in the shaping of expectations, keeping the future open to multiple paths and possibilities. Each of these assessments embeds distinct understandings of how the future will come about, either as a linear development or as multiple options.

There are two consequences to these forms of assessment. The first one is that each of them introduces different performativities of "the hype," because it structures the relations in multiple ways that co-exist. The second one is that, even for consultants, there is no singular theory of hype but different forms of deploying the hype, depending on the public, context and purpose. From the definitions of hype introduced earlier in the framework section, consultants move between (3) hype as an assessment tool which shows their technical expertise, (5) hype as a social phenomenon, in which different actors come together, and (4) hype as a folk theory, i.e. a non-expert way of speaking about expectations and technology futures. For example, a technical assessment of the hype is presented in market reports, devices that are circulated to a broad public. A social interaction assessment occurs in a more intimate space, thus allowing the consultant to establish a personal dialogue with actors knowledgeable in the technology field.

It is this hybrid character of hype that could help to understand how these consultancies operate. I have started with the apparent dilemma that consultants are at the same time optimistic and critical about technology fields. Also, I have shown that they do not constitute a coherent collective that provides clear-cut answers about technology futures. Instead, consultants provide frameworks through which other actors think about and act upon technology. In short, the work of consultants assessing the hype consists in creating specific forms of assemblages of technologies, expectations, actors and practices. In doing so, these promissory actors create a niche for themselves and sustain their activities and continuity in a field. For example, some promissory actors also participate in standardization committees and activities that are explicitly aimed at coordination. One industrial association of graphene producers, the Graphene Stakeholders Associations, was created and coordinated by independent consultants with experience in nanotechnologies. Their activities are frequently supported by others consultants' work. This association is actively committed to speeding up the development of standards in graphene. Similarly, in the case of 3D printing, authoritative consultants such as Terry Wohlers or The Econolyst participate in standardization processes.[109]

[109] For example, these consultants participated in the 2009 Roadmap for Additive Manufacturing (Bourell et al., 2009).

In this paper, I have analysed three forms in which technology consultants assess and assemble the hype. I showed that the relations between actors, technologies and expectations that are deployed in each assessment of the hype differ, as does the agency that is given to each of them. Thus, the hype itself is co-produced with the models, theories and forms of knowledge about it. The forms of assessment of the hype provided by these consultants are used as a means to also shape their own role in these fields. They provide specific images to situations that are experienced by the community of innovation actors as a whole. Consultants move through the hype by enacting it in a variety of forms and contexts, and they also provide means for other innovation actors to shape the spaces in which they can move. These images and discourses are ways of understanding future promises and visions which structure methods of strategic action and intervention. In this respect, they also fulfill a function of anticipatory coordination in the early stages of technology development.

7. Conclusions

> "We will sing of the great crowds who can finally free themselves from the slavery of wage labor and through solidarity revolt against exploitation. We will sing of the infinite web of knowledge and invention, the immaterial technology that frees us from physical hardship. We will sing of the rebellious cognitariat who is in touch with her own body. *We will sing to the infinity of the present and abandon the illusion of a future*"
>
> *Franco "Bifo" Berardi, The Post-future Manifesto (2009) (emphasis added)*

In 1909 the Italian poet Filippo Tommaso Marinetti wrote the "Future Manifesto," a future-oriented poetical piece in which he symbolically bids farewell to the past and welcomes an optimistic future, celebrating industry, speed, machinery, youth and violence. This piece marks the beginning of Futurism, an early 20^{th} century artistic movement (1909-1944) that made "the future" a core motif in art and design, thereby shaping Western ways of thinking about the future for good. A hundred years later, Franco "Bifo" Berardi, an Italian cultural theorist and activist, wrote a new version of the manifesto, "The post-future Manifesto." This new manifesto criticized the way in which an idea of the future that characterized speed, acceleration and urgency has been positioned at the core of capitalist dynamics. The manifesto is also an invitation to halt and question enthusiasm for acceleration, in order to regain a sense of ourselves in the present and disentangle ourselves from a world that requires constant improvement and competition (Nosthoff, 2015).

I start this last chapter with a reference to these two manifestos, because they also capture distinct changes in the way the future of technology has been imagined in recent years, for example under the label of Responsible Innovation. In fact, Berardi's quote obliquely relates to the title of this thesis, "Mindful Anticipation," a title that I have taken from the work of Nordmann (2014) who in turn proposes alternative ways to anticipate technology in society beyond mere predictions. I have chosen this term to characterize my approach to studying how the future is constructed in the present. In this last chapter, I will further develop the notion in light of my empirical findings.

As I stated in the introductory chapter, the aim of this thesis has been to provide insights regarding the way the future of emerging technologies is anticipated, and how this relates to their governance. To this end, I have studied practices of anticipation that have shaped two emergent fields: graphene, and 3D printing. My guiding research question refers to these practices, their performative effects, and the differences between fields:

> What kind of practices shape processes of anticipation in emergent technologies, and what are their performative effects?

In the context of this research question, I will revisit the findings from previous chapters, and further develop my conceptual framework and its implications for theory and practice. This chapter is composed of three parts. In the first part, I summarize the empirical findings and compare the two cases of graphene and 3D printing (7.1). In the second part, I revise and reflect on my conceptual framework, specifying the analytical advantages it offers and its contribution to the literature. I also reflect on the methodological approach that I have used (7.2). Lastly, I provide a general reflection about the implications of this thesis for the practice of anticipation, for the governance of emerging technologies, and for future studies in general (7.3)

In constructing a practice approach to the study of expectations, I have drawn on three sets of literature: the sociology of expectations (Borup et al., 2006), anticipation as treated in human geography (Anderson, 2010), and performativity of socio-technical assemblages (Michel Callon, 2007). In addition, I have used Shove's theory of practices (Shove et al., 2012), Collier and Ong's global assemblages (Collier & Ong, 2005), and the notion of space (Rip & Joly, 2012), as analytical tools to map, characterize and analyze anticipatory practices. I distinguish these two sets of literature because, conceptually, my contribution is focused on the former set, which I refer to as the "conceptual" literature. In particular, I contribute to how they might conceptualize relations between past, present and the future. However, to do so, I draw on some analytical elements from the latter set, which I call the "analytical" literature, in order to make my approach operational and empirically feasible.

The sociology of expectations provides the conceptual background of this study. It draws attention to the performative role of expectations in innovation processes. Starting from this approach, I am interested in understanding the role of expectations in the governance of innovation. In this context, I understand governance not just as normative and explicit attempts to steer innovation through expectations, but in the broader sense of the contribution of expectations to *de facto* governance (Konrad 2010; Rip & Van Amerom 2010; Rip 2012; Konrad & Alvial Palavicino 2015). This set of literature has shown that collective expectations provide guidance, legitimation and coordination in contexts of high uncertainty. However, not enough attention has been paid to the practices that mediate and enable these functions, and how specific forms and instances of performativity contribute to the governance of a techno-scientific field.

Through my approach I have argued and empirically shown that it is not sufficient to merely look at the discourse or rhetoric of expectations. Instead, the way in which expectations are produced and embedded in practices is equally critical to explaining their performativity. Studies of future-oriented expectations have mostly focused on the rhetorical aspect of promises and concerns, explaining how expectations become performative as part of collective discourse. In this thesis, by contrast – and as a way of complementing existing literature – I have chosen to focus on the practices through which expectations are produced, shared, and contested, and on how this relates to innovation processes. This choice was inspired by Anderson's concept of anticipatory practices (Anderson 2007; 2010), a notion used to theorize different modes of future-oriented governance in relation to a potential threat. In Anderson's framework, governance is the result of specific materialities, practices and logics that enable interventions in the present in the name of the future. It can be considered a performative approach to governance, in which "governance" is constructed through the mobilization and shaping of a series of elements that align in a particular way, thus co-producing the world that is "governed." It is also a core claim of the sociology of expectations that future-oriented expectations are performative. Combining these two conceptual perspectives, I have developed a practice approach to understanding future-oriented governance in emerging technologies.

7.1. Summary of empirical findings

7.1.1. Overview of the empirical Chapters

In three empirical chapters, I have addressed different aspects of anticipation in graphene and 3D printing. In Chapter 4, I focused on the emergence of the graphene field and the role of future-oriented practices, with two research questions: *Which practices are deployed in creating, shaping and circulating expectations about graphene in particular spaces? How have these practices shaped the graphene field, i.e., what is their performative effect, and how does this modify existing spaces?* To answer these questions, I have analyzed how a variety of anticipatory practices contributed to the development of graphene as a socio-technical field, and how spaces evolved accordingly. By the term *space*, I refer to a specific configuration of actors, practices and rules that is characteristic of techno-science, such as the high-impact journal publishing system, startup culture, etc. In this chapter, I used the figure of the graphene hype to draw attention to the way in which connections emerge between diverse spaces, e.g. science, policy, the market, and risk assessment. By reconstructing the case of graphene, I revisited the common assumption that hypes are an unavoidable component of science-driven technological innovation, (e.g. in which a particular scientific discovery is turned into a technological field). I showed the background conditions that enable and give form to hypes, as the result of the assembling of different anticipatory practices. In this process, new connections between spaces emerge, driven by the active and strategic use of expectations by technology actors.

To say that the distinction between spaces, such as science and the market is blurring, is not new. Many scientists today are encouraged to become entrepreneurs, and policy actors are active in promoting such processes (Shapin, 2009). What I add to this discussion is that the process itself is not just about making connections through expectations, and not just about blurring the boundaries between spaces. Instead, I argue that when connections emerge, there is also an active attempt to keep the identity of these spaces. That is to say, if an anticipatory practice creates connections between spaces, it nevertheless has a different meaning, function and even performative effect for each space. An example is the production of market reports, which is a practice of technology consultants and is tailored to the investor community. For investors, the market report serves to legitimize a specific company and/or technology and their willingness to invest in it. Nevertheless, these market reports are also relevant to the scientific and technological research community, who see them as a signal of the maturity of the general field. In their case, it is not about specific companies or technologies, but about the general evolution of the field.

Secondly, I have argued that there are particular ways of anticipating for each actor group. For example, I have shown how the development of a graphene roadmap in the context of the Flagship project is related to established anticipatory practices (such as the semiconductor industry's ITRS roadmap) and how it mobilizes other practices for its development: scientific publications, conferences & meetings, and even the work of specialized intermediary organizations. While it might seem self-evident that such complex practices are the result of many other local practices, I have shown how this process of bringing together practices is important to iteratively define the spaces in which an emergent field is constituted. Again in relation to the graphene flagship, I argue that this space is more than a large funding scheme: it is a way in which scientists' expectations about graphene and policy makers' expectations about governance modes of European science and technology meet. Such spaces encompass the engagement of industrial and other private actors for the development of technologies, the governance of risks and the creation of research linkages among different European countries. There are practices that are local, but also practices that connect between the local and the global.

In Chapter 5, I studied in detail the specific socio-material practices through which anticipation takes place in 3D printing. I focused on the question, *which material practices shape expectations about 3D printing, and which logics guide these practices?* In this case, I do not describe the field as a whole, but rather I focus on a set of Dutch companies and their visions, strategies and anticipatory practices. 3D printing has been framed and made popular through ideas of its revolutionary potential, embodied in visions such as the "third industrial revolution" (Rifkin 2011; Anderson 2012). In this narrative it is implied that a logic different from the one of "the market" guides and shapes the future of 3D printing. I explore and question this assumption by analyzing the logics that guide the anticipatory practices in which three Dutch 3D printing companies engage.

The different ways in which actors relate to the future through these practices are what I call anticipatory logics. I argue that for 3D printing, there are at least two logics that guide anticipation: a dominant, market-related techno-economic logic and an open source logic that emerges from makers and hacker communities. I argue that these two logics coexist, guiding different aspects of their development. So while a practice such as the organization of communities or "hubs," as in the case of the company 3D Hubs, is in principle deployed to empower users and user communities, such empowerment simultaneously serves to expand the market penetration and market dominance of this company. However, different logics do reflect different ways in which "the future" can be understood, modified and anticipated. An open-source logic stresses the reflexive and iterative enactment of these futures by constantly questioning the choices that are made in relation to specific expectations, and by reshaping how these logics are embedded in material practices. In contrast, a techno-economic logic assumes certain "facts" about a future (such as that the technology is promising, the risks are imminent) and aims to control and/or take advantage of these facts without leaving space to question their grounds. In this respect, I show how broader political considerations about how a field should be governed play out at the local level and through material practices.

In Chapter 6, I studied a particular type of "promissory actor" known as the technology consultant, and examined their role in articulating technology futures. These specialized actors are present in both the fields of graphene and 3D printing. Because of their particular role in the articulation of markets for emerging technologies, and the very specific practices in which they engage, I dedicated full attention to them in this last empirical chapter. I focused on a set of interrelated promissory actors in each field, their interactions, and the ways in which they produce future-oriented expectations. In particular, I analyzed the different ways in which the figure of a hype-cycle is deployed through their anticipatory practices. I presented three forms in which the figure of the hype is assessed and deployed: as technical expertise, as social dynamic, and as a space for interaction. These forms vary in the exact ways in which different elements are assembled in "the hype," shaping what can or cannot be done in relation to a field in specific ways. I showed that, (i) such promissory actors play a central role in articulating expectations across different spaces and actor groups through practices such as the production of market reports, technology conferences and technology benchmarking; additionally, I showed that (ii) these actors create and establish their own agendas for the field through the development of tentative structures embodied in specific expectations. By doing so, they safeguard their role and position by creating the need for their particular expertise. Interestingly, these networks of promissory actors operate in similar ways in graphene and 3D printing, being particularly relevant for market actors, but also influencing the activities of scientists and policy makers. In both cases, they play an important role in anticipatory coordination by setting up tentative structures of the field.

7.1.2. Comparison between the two cases

As detailed in Chapter 3, these two cases represent, in principle, two different forms of anticipating the future, related to the notions of the *regime of economics of technoscientific promises* and the *regime of collective experimentation* (Felt & Wynne, 2007; Joly, 2010). Starting from this assumption, I will now summarize and compare the main anticipatory practices that I observed in these two cases, and the forms and characteristics of the hype for each technology. I will show that just as there are important differences, there are also strong similarities between them.

The types of anticipatory practices and logics observed for each technology are closely related to the spaces where they develop. I will compare the anticipatory practices for different spaces in each case, looking for commonalities and differences. The most immediate difference comes from the communities where these technologies emerged. While graphene emerged from academic research, 3D printing (i.e. the consumer 3D printer) developed in maker communities. These two groups of actors have very different and distinctive ways of constructing the future of these technologies. Graphene scientists, as characterized in Chapter 4, use for instance high-impact publications to promote expectations about a technology and to market their own research. This practice is reinforced by a system of grants and academic careers that are evaluated in terms of publications and their impact. I explored the world of promises that is built in high impact journals, and how a dynamic that reinforces this promissory behavior emerges between scientists, editors and funding bodies. In the case of graphene, the journal Nature became actively engaged in the promotion and definition of the field, followings its scientific, technological and even political developments, particularly in relation to the Graphene flagship. In such practices, promises are voiced as part of publications, news, editorials, etc.; however, they do not need to be substantially supported by other practices, (e.g. by the development of prototypes) and the publications themselves become the medium for the expectations to circulate. This form of anticipation contrasts with the types of anticipatory practices that are more relevant for maker communities associated with 3D printing. While there is a very strong rhetorical activity about how revolutionary the technology is, sharing expectations happens through the development of prototypes, designs, legal frameworks, and technologies in general. That is to say, while the circulation of expectations in graphene occurs in the scientific community through narratives and speech, for members of the 3D printing community it occurs through material objects. The source of legitimacy of the expectations, attached to the practices, is therefore different.

Interestingly, and in contrast, the way policy actors engage in the future of each of these technologies is not so radically dissimilar. In both cases, explicit anticipatory practices are relevant to connecting policy with other spaces. In the case of graphene, the graphene roadmap (a scientific roadmap) legitimizes the activities of graphene researchers in the policy domain and improves their ability to coordinate among themselves, which contributed to the success of the flagship application. In the case of 3D printing, this technology resonates in policy circles with broader narratives of the future of European society, which emerge in the context of foresight exercises: circular economy, makers, new economic models, self-dependency, etc. Framed in this way, the technology has an impact in many areas, from regulation, to safety, consumer rights, liability, new business and production models, etc. In both cases, explicit anticipatory practices are required to position these technologies in the policy agenda and structure intervention. However, the type of practice itself varies. A foresight exercise is much more "open" than a roadmap, in the sense that it does not require a clear path for the future, but rather allows the exploration of multiple possibilities. This might be a reflection of the perceived complexity of the issues 3D printing encompasses, in contrast to graphene, which is not attached so strongly to radical narratives of society.

As for regulators and standardization bodies, they operate quite similarly in anticipating both 3D printing and graphene. It could be said that the practices related to regulation and standardization are themselves future oriented, but that they anticipate these technologies in a relatively narrow way, through the lens of predefined forms of standardization, risk assessment and so on. For this reason, their community (composed of regulators, standardization bodies and experts, and risk experts) and practices do not vary strongly from one technology to another.

Market actors, on the contrary, show commonalities and some differences. In graphene, venture capital and funding come as a result of roadmapping, patents and, largely, speculation about promises; in 3D printing crowdsourcing plays an important role. One can consider that in principle these two practices to obtain funding are similar: funders bet on the promises of a startup company based on specific forms of legitimacy. In graphene and with venture capital this is the result of long negotiations, expert consultations and is validated by market reports, roadmaps and patents. In contrast, in crowdsourcing this process is more open to the public, and expectations are spread through videos, media and technical specifications. In this context, pursuing open source strategies (instead of having a patent) becomes an asset. On the basis of this characterization it can be speculated that crowdsourcing is more prone to overpromising and hype than conventional forms of early-stage technology funding such as venture capital. This point has in fact, been raised by actors in 3D printing who argue that crowdfunding is damaging the credibility and coherence of the technology (see Chapter 5).

Lastly, intermediary organizations such as technology consultants play a role in both cases, and for these organizations their practices are quite similar in the two fields. They are particularly important in arranging markets for these technologies, and their structure and practices are almost the same irrespective of the technology they are working with. Similar to standardization and regulation bodies, it is possible to argue that these organizations are largely future-oriented and they find their niche in a variety of technologies of diverse nature. They have specific ways of building their legitimacy and proving their expertise in a field, and these are not so much related to the specificities of the technology as to the ways in which they relate to other innovation actors and mobilize collective knowledge about a field.

In addition to the specific differences in their practices, a broader consideration relates to whether hypes in graphene and 3D printing are different, and why. As I showed in the case description, these two technologies are going through a hype phase, characterized by strong attention and enthusiastic promises. There are some similarities between the cases: in both, we observe that the hype connects between different spaces and different logics of anticipation. In fact, the hype is the result of practices that bring together expectations from different spaces and actor groups, but it is much more than the practices themselves: in both cases, hypes have been strong enough to mobilize large public and private support and resources. In the case of graphene, the hype has moved from the science space into policy and market. For 3D printing, the hype has moved from maker communities into industry and later policy. However, in contrast to the hype in graphene, in 3D printing we see some agreement in guiding visions among a diverse range of innovation actors, while the specific expectations retain their diversity and are even highly dissimilar. This last point is interesting in relation to the resilience of technologies to disappointment. As has been argued elsewhere (Ruef & Markard, 2010; van Lente et al., 2013), a higher diversity of expectations gives more opportunities for technologies to reinvent their future-oriented narratives, and makes them less prone to disappointment. While one could speculate that 3D printing is, in that respect, more resilient than graphene, it is too early to know with certainty.

From the cases it is hard to assess accurately how much each type of anticipatory practice contributes or is more prone to hype. Since the case selection was done considering technologies that are going through hype, I expected that the practices observed are more hype-oriented. However, going against the common wisdom that hypes are the result of media-exaggeration, I have shown that the hype is not only the result of media exaggeration, but that each specific anticipatory practice contributes to hype to some extent. In fact, even for practices of "collective experimentations" such as crowdfunding, there is a strong tendency to overpromising and hype. The phenomenon is so pervasive that one could argue that it is intrinsic to techno-scientific practices and it is hard to dissociate from the production of new technologies. As a matter of fact, hypes seem to fulfill a social function and to be unavoidable, even necessary, for early-stage technology development. However, not all hypes result in short-term technological development with a desirable impact on society. Some hypes, such as the one on high temperature superconductivity, seem to have run its course without resulting in any longer-lasting results (Felt & Nowotny, 1992). Nevertheless, technological fields keep developing, even if less coordinated or under different names, leading to potential results in the long run (De Liso, Filatrella, Gagliari, & Napoli, 2014). It is reasonable to ask, then, what it means – or even if it is possible – to do "responsible hyping." I will go back to this point in section (7.3).

As I have discussed in Chapters 4 and 6, a perceived hype leads to forms of anticipatory coordination. When actors in the field perceived and agreed that there is a hype going on, they coordinate their activities in order to control expectations, to avoid overpromising and especially to avoid disappointment. As explained in Chapter 6, intermediary organizations in particular use the figure of the hype in order to structure a discussion about promises, expectations and future-oriented activities in general, and position themselves in this discussion. This is framed by these organizations as the need to develop strategies for anticipatory coordination, as seen in the case of graphene with the Graphene Stakeholder's association, but also to some extent with 3D printing in their exploration of new forms of governance.

7.2. Contributions to existing literature

I have developed a conceptual approach that aims to contribute to the study of expectations and anticipation in emerging technologies. This approach is based on the notion of anticipatory action (Anderson, 2010), which is an approach aimed to understand the governance of future threats and risks, through the knowledge, practices and materiality in which anticipation of such threats is produced. Taking the conceptual background of the Sociology of Expectations (Borup et al., 2006), I have further developed the notion of anticipatory practices, particularly for the case of new and emerging technologies.

The notion of anticipatory practices also relates to other sets of literature related to techno-scientific futures. The role of anticipation in innovation processes has been extensively described and highlighted (Rip, 2012), including its role in the development of methodologies and tools for steering innovation in desirable directions (Barben et al., 2008). Against this background, I introduce and develop an approach that seeks to understand how local and situated forms of anticipation translate to global patterns, which affect the structure and governance of emergent fields. In other words, by this approach I seek to understand how local and situated future-oriented practices, in combination, shape emergent technological fields at large.

This approach has two loci of attention: *anticipatory practices* and their *interactions*. Firstly, it focuses on how expectations are made, shaped and circulated in practices, in a certain context – a certain space. Secondly, it pays attention to how these practices are mutually related, to how they come to interact, and to the performative effects of this interaction. I argue that one way of conceptualizing the relations that emerge between anticipatory practices and the way they co-produce expectations about a technological field is through the notion of assemblage. This notion stresses that there are interlinks between practices, and that these interlinks have particular effects that are more than just the sum of their parts. This means that, for one thing, the performative role of expectations is more than just the result of the strategic activities, but also that there are further unintended and collective effects that shape the field.

Thinking in terms of an assemblage of anticipatory practices stresses that expectations have dynamics of their own, related to, but distinct from, innovation processes. This distinction relates to the notion of *governance of and by expectations* (Konrad & Alvial Palavicino, 2015), which characterizes the relation between the dynamics of expectations and innovation processes as a reflexive relation, in which expectations have an effect on innovation dynamics and vice versa. In this respect, an assemblage can be understood as a form of anticipatory governance because it embodies a particular arrangement that includes multiple contingent and specific forms of anticipation. Concretely, each technological hype-cycle can be considered an assemblage of its own, bringing together actors, technologies, practices and other elements that configure technological fields in ways that are similar yet unique for each technology. Each hype has its own temporal and spatial dynamics of expectations, and specific forms in which expectations contribute to de facto governance. Along these lines, it is possible to argue that in order to steer expectations and, consequently, innovation processes, one could think of governance of hypes. This means more than explicitly steering promises and expectations in order to avoid or reduce hypes, (because, as I have argued, hypes fulfill a function and are to some extent unavoidable), but rather, paying attention to, (i) the anticipatory practices that contribute the most to a particular hype, (ii) the space they belong to, and (iii) how innovation actors of different spaces engage with a certain practice and its de facto governance effects. In this way, it is possible to steer anticipation not by attempting to change the narratives and rhetoric about a new technology in a top-down way, but rather by changing the practices through which these narratives emerge and are positioned. One can argue that this is in fact the approach used by Anticipatory Governance or Technology Assessment practitioners; however, what I propose is not just to add new practices, but rather to attempt to change relevant practices from within in order to experiment with possible futures. One example of this idea is Erik Fisher's work on laboratory engagement work that seeks to introduce practices allowing scientists to become reflective about their own choices (Gjefsen & Fisher, 2014).

The notion of assemblage and space as presented in this thesis relates to how expectations and anticipatory practices reconfigure existing innovation structures and configure new fields. This perspective pays attention to both the temporal and the spatial evolution of expectations (Birch, 2012; Kearnes, 2013; Milne, 2012), understanding that expectations do not only have an effect on time but also spatial effects. Space, in this context, is used both to refer to a certain actor group and their respective set of practices, rules, and structures (Bakker, van Lente, & Meeus, 2011; Rip & Joly, 2012) and to highlight that these spaces exist physically and have a particular materiality, which evolves with the space itself (Anderson, Kearnes, & Doubleday, 2007; Kearnes, 2013). I argued that in each of these spaces, there is a dominant way of doing anticipation, which explains the ways in which expectations are performative in a certain space. Following this logic, the formation of a technology field comes as a result of bringing these spaces together into new configurations, constantly adapting to one another. Such a process might include either bringing together existing practices that usually operate together, (for example, a university invention that is turned into a start-up to create value from the potential of a discovery), or creating new practices that are dissimilar and that create new connections between spaces, or new hybrid-spaces, (such as citizen DIY-labs where the public can assess the risks of new technologies). The process of creating spaces of anticipation through the alignment of practices is not a linear process; various spaces coexist at the same time and they evolve accordingly.

In selecting the technologies that I took as case studies, I was guided by the notions of regimes of economics of techno-scientific promises and of collective experimentation. In foundational descriptions of these two "regimes" of innovation (Felt & Wynne, 2007; Joly, 2010), it is implied that the future is a core element of the first and supposedly dominant regime, but not of the regime of collective experimentation. Through my case studies I have firstly shown that innovation processes are actually a combination of the two regimes (with multiple logics), and secondly that the future is present and pervasive in both regimes of innovation, albeit in different forms. The anticipatory practices for each regime are very different. While in one case promises are highly rhetorical and align with incumbent interests, in the other one expectations are embedded into material practices and are shared as part of these practices. In this latter case, the narrative is as important as the actual doing in order to share and spread a specific future vision.

In addition to these conceptual contributions, I have explored the use of both digital and conventional ethnographic tools for the study of expectation dynamics. As I detailed in Chapter 3, I have especially focused on the use of social media (Twitter, LinkedIn, Reddit and forums) for the spread and shaping of expectations in a field. I have not only analyzed these platforms, but I have become an active participant in some of their discussions. Briefly, this approach to expectations enabled me to "easily" become familiar and visible among innovation actors who were relevant for my study. I could connect to discussions that were taking place geographically distant from my location; also, I could notice and learn about the role of intermediary actors (consultants, website managers, independent experts) that were not part of my initial assumptions of the field, but who appeared to play a very important role in both cases. However, to pay constant attention and be visible in social media is very time consuming, since it requires being attentive to discussions almost every day, and participating in them often. In addition, becoming an active participant of the discussions brought me close to some of the actors of the field, thus prompting me in turn to make an effort to maintain my neutrality as a researcher so as to avoid creating "artificial" results based on my own agency. Third, the digital only shows a part of the picture, and in order to really understand how these communities and their futures are constituted one must also engage in conventional ethnography, ideally participating in their gatherings and events (Pelizza, 2010a).

7.2.1. Reflections, limitations and future work

In this last section, I contextualize the contribution of this thesis in relation to the broader discussion of the future and governance of emerging technologies. This area has been a topic of extensive research, both in academic and policy circles. Under the names of responsible research and innovation (Owen, Macnaghten, & Stilgoe, 2012), anticipatory governance (Barben et al., 2008), and others, there are increasing attempts to understand how emerging technology fields are shaped and how to steer this process into desirable directions. While my thesis is not directly aimed at producing methodologies for anticipation, or prescribing better ways to anticipate technologies in society, I will sketch some contributions to this discussion based on my empirical findings.

7.2.2. What does it mean to do "mindful anticipation"?

To answer this question, I will go back to the title of this thesis, "mindful anticipation." Nordmann (2014) has discussed the "mindfulness" of anticipatory governance and responsible innovation by asking how these approaches bring attention to the consequences of actions and events of which we are responsible. In this context, mindfulness comes as a critique of attempts to actually know the future, i.e. to be able to anticipate what is going to happen based on some form of knowledge. Specifically, Nordmann criticizes the idea that the future can, by any means, be known and controlled as a consequence of something being done in the present. Instead, and in the same spirit as Bernardi's Post Future Manifesto, what we can "know" (and consequently, shape) are the promises, visions, projects, anxieties and practices in which we frame the future today. It is these ways of seeing and embodying the future in the present that we should call into question. This means that instead of expecting to know the future, we should ask whether the ways in which we think of possible futures today are the right ones – regardless of whether we think they are the most plausible. Since my attention is given precisely to the ways in which the future is embodied in the present, I have entitled this thesis "Mindful Anticipation."

Based on this "mindful" perspective, I introduce some recommendations with respect to anticipation and governance of emergent technologies.

(i) Mind the present. As I have shown and argued, there are specific ways in which the future is embedded in practices characteristic of different spaces. These are particular ways of articulating and sharing expectations, which have specific forms of performativity. Such forms of anticipation are the result of multiple temporalities that converge in a space: there exists a certain history and path-dependency – there are ongoing developments in the present that both affect and co-exist with future expectations. Introducing new practices to a space, such as a foresight exercise, or translating new practices from a different space, require taking into account the contextual conditions under which practices are performative. This is the case because these forms of acting in relation to the future have less to do with the future and more to do with the way in which specific actor groups deal with fundamental uncertainties and relate to one another and to technological developments in the present. Creating and introducing practices that bring spaces together should be done by paying attention to idiosyncratic forms of anticipation, and by allowing for adaptation and stabilization of emergent and hybrid spaces. This process is not only top-down, but it is also the result of the same interactions among innovation actors who constitute spaces. For that reason, time is required for experimentation with new practices and the way they re-shape spaces.

(ii) Encourage diversity. It has been already argued that a diversity of expectations is beneficial for the resilience of a technology or technology field, particularly in the phase of disappointment cycles (Konrad et al., 2012; Ruef & Markard, 2010; van Lente et al., 2013). In addition to encouraging different and even contrasting expectations for emergent technology fields, I would recommend using a diversity of methods, methodologies, practices and temporalities to engage with the future. Particularly for foresight, CTA, or scenario exercises that aim to meaningfully engage with a diversity of publics, my results would suggest a variety of methods to make visible and explicit the ways in which actors engage with the future. Such an approach goes beyond just imagining and speaking about the future, to actually developing fictional prototypes, legal frameworks, narratives and foundational stories that tell us more about how to get to a desirable state and about the underlying forces involved, than about the future itself. Sometimes talking about the future means talking about the past, and thinking of how we have arrived here, to unveil the assumptions and temporalities involved in future thinking which might vary strongly among actor groups.

(iii) Allow experimentation with non-explicit futures. Much of the policy-related anticipation happens in explicit initiatives that aim to capture the way in which a certain actor group (scientists, the public, industry, etc.) thinks about the future. While there is a value in opening up these explicit processes to a wide range of publics, I suggest adding two approaches to understand how future directions are taking place in the present. This is because a strong diversity of publics might not necessarily translate into a diversity of futures that represent these publics. The first is to engage in "ethnographies of the future," studying the way in which the future is embedded in everyday practices, with their different aims, frames, spaces and temporalities. Such mapping of the future can inform processes of decision-making and particularly of intervention. And the second, related to intervention, is to allow the future to emerge from the non-explicit, from interventions that do not directly speak about it, but that make us reflect about the way we relate to it. The future is profoundly uncertain and even scary; but thinking about the future can also be achieved by reflecting on the past, about change, variation and emergence. The approach I recommend in fact fits with the idea of "design fiction", in which anticipation is conceptualized as a process of design. "Future assemblages" here are literally brought into the present as artifacts, narratives, and demonstrations (Bleecker, 2009). These designs would be based on the empirical study of embedded futures, found in unconventional places, and would be used to encourage participants to think about the future beyond the obvious. In this way, requirements for plausibility, coherence and consistency are left out of the process in early stages, thereby creating futures that circumvent dominant ways of thinking.

(iv) Go beyond plausibility. The future cannot be known, but it can be opened up through the practices in which it is embedded, in order to think about and shape it in forms that are more transparent, responsible, sustainable and democratic. In that respect, it is hard to think in terms of the plausibility of a future when it comes to the long term, because of radical uncertainties, and because plausible futures might limit our ability to think outside the box in a way that meaningfully mobilizes action. Futures are often radically different from what we can possibly hope to predict, and they are lived within societies that may be radically different from our own, present society. One could say that futures even need to be radically different in order to create meaningful engagement. If the future is a linear continuation of the present, then there is no way out and there is no point in anticipating it, at least not in an open way. Thus, I would argue for allowing exceptions, radicalness, and implausibility in our thinking about the future. We should allow emotions and affects to be part of imagining the future. Thinking beyond plausibility is a necessary step to meaningfully change the future.

7.2.3. Limitations and future work

I have explored the world of practices involved in anticipation, taking a broad perspective in which I have looked not just at explicit anticipatory practices but also at how anticipation is embedded in the everyday making of a techno-scientific field. However, it is important to note that my accounts of what constitutes an anticipatory practice are limited by the cases that I have selected. While these cases represent two different modes of anticipation, other cases are underrepresented: established technologies that have gone through many hypes such as solar energy or fuel cells, “failed” technologies such as high temperature superconductivity, or technologies that do not get strong media attention such as agricultural innovations used in the developing world.

Nevertheless, this kind of approach opens up some interesting lines for further inquiry. In addition to exploring different kinds of technologies, further research should look at how different forms of anticipation have developed historically and how they have contributed to shaping particular types of technology. It could be expected that, just as forms of explicit anticipation have changed through the years, the way in which the future is anticipated in techno-scientific practices has also varied. This type of analysis could add to the “history of the future,” so as to understand how our relation with the future and with new technologies has evolved over time.

A second area of further research relates to the role of specialized expectations actors (technology consultants, technology bloggers, independent experts, etc.) who contribute to shaping emerging fields. In fact, it would be worth paying attention to intermediary organizations and their own anticipatory “ecosystems,” how different types of promissory actors interact with each other, and how they keep a portfolio of emerging technologies in which they develop their anticipatory activities. While there is an extensive work on consultants, more attention should be given to their anticipatory strategies and their particular ways of constructing the future.

Finally, I have explored the use of digital and social media from the perspective of expectations, showing that expectations are shared and shaped through new media. This is a domain that, with a few exceptions (Fordyce, 2015; Schneider, 2015), has remained unexplored for sociologists. The dynamics of expectations observed in the digital realm can be very different from what happens in the “real world,” as well as methodologically speaking (Boyd, 2013; Coleman, 2010). As I observed, appearing as an expert and being recognized by a community seems to be easier in the digital world. It is also possible to passively “observe” how expectations are being shared and shaped, without taking an obvious stance or perspective. My research suggests that digital media has become an important space for the circulation of expectations and particularly for the creation of linkages between different actor groups (for example, scientists and investors, or developers and the general public). In fact, a number of online tools allow for “participation” to collectively shape the expectations about a technology, as seen in the case of the online discussion over the graphene roadmap, or the forums of 3D printing licenses. Such tools can be tailored and used for methodologies such as technology assessment. In conclusion, a systematic analysis of the “digital life” of expectations could help answer these and other questions.

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Annexes

A. Annex: List of Interviewees

A.1. Interviews: Graphene

Number	Description	Format	Date	Country
1	Consultant and member of industry association, former scientists in nanotechnology. Roadmap advisor.	Skype	12/12/2013	US
2	Researcher in bionanomaterials, with focus on risk issues	Skype	21/01/2013	NL
3	Researcher and Coordinator of the Graphene Flagship	Phone	21/05/2013	IT
4	CEO graphene company	Phone	10/09/2013	ES
5	Researcher in a Standards organization dealing with graphene	Skype	07/01/2014	UK
6	CEO graphene company	Phone	03/09/2013	NO
7	Policy maker related to FET Flagship Scheme	Phone	17/06/2013	EU
8	CEO graphene company	Skype	18/12/2013	US
9	Consultant and coordinator of industry association	Skype	12/08/13	US
10	Graphene researcher and blogger	Skype	16/06/ 2013	ES
11	CEO graphene company, member of the Flagship	Skype	26/03/2013	ES
12	Researcher in Graphene for electronics, non-flagship	Skype	25/06/2013	IT
13	Researcher in new materials	In person	08/01/2013	NL
14	Consultant from an important consultancy organization	Skype	18/07/ 2013	UK
15	Researcher in Graphene for Electronics	Skype	06/06/2013	BE
16	Researcher and Coordinator Graphene Flagship	Phone	13/01/2013	SE

17	Researcher in graphene, owner of a graphene startup	In person	01/02/2013	NL
18	Researcher in graphene physics	In person	31/01/2013	NL
19	Researcher in graphene for electronics	In person	31/01/2013	NL
20	CEO graphene company	Phone	26/09/2013	ES
21	Researcher graphene in photonics	Skype	17/02/13	NL
22	Policy maker from FOM	Skype	05/03/2013	NL
23	Journalist, editor and science communicator	Skype	04/07/2013	UK
24	Journalist and editor	Skype	28/06/2013	UK
25	Researcher in graphene for electronics	In person	07/02/2013	NL
26	Flagship coordinator of Innovation and IP	Skype	10/09/2013	SE
27	Ex-CEO graphene company	Skype	20/12/2013	US
28	Blogger and website owner	Email	12/12/2013	IS
29	Consultant in Nanotechnology	in person	11/12/2013	UK

A.2. Interviews: 3D printing

Number	Description	Type of interview	Date	Country
1	IP expert in new technologies	Phone	21/08/2014	NL
2	Consultant in Printed electronics	Skype	03/04/2014	NL
3	Researcher in bio 3D printing	In person	17/07/2014	NL
4	Researcher 3D printing	In person	20/08/2014	NL
5	Fablab member	In person	26/09/2014	NL
6	Independent consultant and community manager of 3D printing site	In person	22/10/2014	NL
7	CEO company, former RepRap	Skype	03/11/2014	NL
8	Consultant and FabLab activist	In person	08/10/2014	NL
9	Policy maker from DG Connect	Skype	24/11/2014	UK
10	Independent consultant specialized in 3D printing	Phone	17/11/2014	UK
11	Community manager of 3D printing company	In person	28/11/2014	NL
12	Policy maker from DG Connect	Phone	03/12/2014	FR
13	Director of makerspace and media activist	In person	21/11/2014	NL
14	Researcher in 3D printing	Phone	20/10/2014	SE
15	Coordinator of FabLab	In person	12/09/2014	NL
16	Community and Media Manager of 3D printing company	Skype	26/02/2015	NL
17	Researcher STS in 3D printing and grassroots organizations	Skype	21/03/2015	UK
18	Researcher 3D printing online communities	Email, Twitter	16/01/2015	AUS

B. Annex: Social Media

B.1. Most Relevant Twitter Accounts: Graphene

Name	Twitter ID	Description
Graphenea	@graphenea	Company
Graphene Labs	@GrapheneLabs	Company
Tim Harper	@tim_harper	Consultancy
IDTechEx	@IDTechEx	Consultancy
Khasha Ghaffarzadeh	@khashaG	Consultancy
Graphene Tracker	@graphenetracker	Investment website
Graphene Technologies	@GrapheneTech	Company
Graphene-Info [200F?]	@grapheneinfo	Website
Graphene Flagship	@GrapheneCA	Flagship project
nanofutures	@nanofutures	Intermediary organization
Joerg Heber	@joergheber	Nature editor
Richard Noorden	@richvn	Nature editor
Phillip Bal	@philipball	Nature editor
Lomiko Technologies	@apaulgill	Investor
materialstoday	@MaterialsToday	Journal, material science
IEEE Spectrum	@IEEESpectrum	Journal, electronics
2-DTECH	@2DTECH	Company
Nanoco	@nanocotech	Company
Graphene Stocks	@GrapheneStocks	Investment
Graphene Technologies	@grapheneTech	Company
Graphene Week	@GrapheneW	Conference
Vorbeck	@Vorbeck	Company

GRAFOID	@GRAFOID	Company
Andrea Pochylova	@Agraphene	Consultant
Andrea E. Reinhardt	@minamnanofuture	Intermediary organization
Graphene Summit	@GrapheneSummit	Conference
Andrew Kerry	@Andrew_J	Consultant, conferences
Graphene 3D Lab	@Graphene3D	Company
Christian Martin	@chrstinmrth	Consultant
Alan Rae	@IncWorks_Fan	Consultant / investment
Graphene Sage	@graphenesage	Conference
Dexter Johnson	@thenanoclast	Consultant / IEEE journalist
Stefano Tonzani	@tonzani	Editor material science
Vasco Teixeira	@Vasco_Teixeira	Researcher
Alan Rae	@IncWorks_Fan	Consultant / investment
Wilfred van der Wiel	@WGvanderWiel	Researcher
KTN Nano	@KTNUK-Nano	Intermediary organization
Cientifica	@CientificaLtd	Consultant / investment

B.2. Most Relevant Twitter Accounts: 3D printing

Name	**Twitter ID**	**Description**
Richard H	@RichRap3D	Maker
Frederik Lean	@FredLean	Consultant
YouMagine	@YouMagine	3D printing platform
techfortrade	@techfortrade	NGO
Spark 3D printing	@Spark3DP	3D printing platform
Matt Ratto	@mattratto	Researcher

Cut price theory	@robbiefordyce	Researcher
Ultimaker	@Ultimaker	Company
Futurium	@FuturiumEU	Policy
Simona Ferrari	@FerrariSim	Company
Thomas Birtchnell	@tbirtchnell	Researcher
Jordan Brandt	@gordobia	Consultant
Adam Watson Brown	@awb58	Policy
Markeen Vogelaar	@MarleenVogelaar	Company
Joris Peels	@piltz	Consultant
DigitalFabricat	@ DigitalFabricat	Researcher / consultant
Enabling the Future	@enablethefuture	NGO / community
Peter Troxler	@trox	Consultant / FabLabs
Ernst-Jan Louwers	@EJLouwers	Lawyer, intellectual property
Stratasys consulting	@3DPrintpeople	Consultant

B.3. LinkedIn Accounts and Groups: Graphene

Name of the Group	**Description**	**URL**
Graphene Stakeholders Association	Industry association of graphene companies and related (approx. 200 members)	https://www.linkedin.com/groups/4885404
Graphene Council	Industry oriented community that discusses graphene innovation and application (>5,000 members)	https://www.linkedin.com/groups/5153830
NanoMaster Project	Discusses the NanoMaster project, a FP7 project on graphene. (approx. 100 members)	https://www.linkedin.com/groups/4216400

2D Advanced Materials (Graphene, MoS2, BN, WS2 and much more)	Discusses R&D in graphene and related 2D materials (approx. 1,000 members)	https://www.linkedin.com/groups/4721831
Graphene Society	Industry oriented discussion about the application and possibilities of graphene (approx. 3,500 members)	https://www.linkedin.com/groups/2072700

B.4. LinkedIn Accounts and Groups: 3D Printing

Name of the Group	**Description**	**URL**
From 3D Printing at Home to Additive Manufacturing	Discusses applications and market developments on 3D printing. (approx. 4,700 members)	https://www.linkedin.com/groups/3953970
3D Printing	Discusses 3D printing, Additive Manufacturing and Rapid Prototyping developments. Very numerous group (> 33,000 members)	https://www.linkedin.com/groups/792077
3D Bioprinting & 3D MedTech Printing Forum	3D printing in tissue engineering, implants, and other medical applications (> 300 members).	https://www.linkedin.com/groups/4820877
3D Printing Materials Forum	Developments in 3D printing materials (> 300 members)	https://www.linkedin.com/groups/8138197

C. Annex: Events

C.1. Events: Graphene

Name	Date	Place	Type
Graphene 2013	23 to 26, April 2013	Bilbao, ES	Scientific conference
Graphene Stakeholder's Association Summit	October 17, 2013	University of Pennsylvania Philadelphia, US	Business meeting
INC9	May 14-17, 2013	Berlin, DE	Scientific / business

C.2. Events: 3D printing

Name	Date	Place	Type
3D Printing Event	19-20 June, 2014	Maastricht, NL	Scientific conference
Euromold	25-28 November, 2014	Frankfurt, DE	Business meeting
Dutch Design Week	18-26 October, 2014	Eindhoven, NL	Design Conference with emphasis of innovative uses of 3D printing. I attended several talks and shows, and also joined a visit to the Shapeways factory

D. Annex: Documents and Websites

This annex lists data sources for the analysis quoted in this dissertation. Note: these are not all the sources revised, but the ones that were actually quoted.

D.1. Graphene

Name	Type	Reference (URL)
Graphene: safe or toxic? The two faces of the medal	Review paper	(Bianco, 2013)
Stability and transport of graphene oxide nanoparticles in groundwater and surface water	Research paper	(Lanphere et al., 2014)
Perspectives on the 2010 Nobel Prize in Physics for Graphene	Review paper	(Dresselhaus & Araujo, 2010)
Prof. Andre Geim Interviewed about Graphene	Video	https://www.youtube.com/watch?v=klypYRR49BU
Graphene: New bridge between condensed matter physics and quantum electrodynamics	Review paper	(Katsnelson & Novoselov, 2007)
Graphene: The worldwide patent landscape	Report prepared by the UK Intellectual Property Office	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/312676/informatics-graphene-2013.pdf
Bringing Reality to the Hype, the Total Graphene Market Set for a Modest $126 Million in 2020	Blog entry by Lux Research (consultancy)	http://blog.luxresearchinc.com/blog/2013/03/bringing-reality-to-the-hype-the-total-graphene-market-set-for-a-modest-126-million-in-2020/
Graphene: The Quest for supercarbon	Nature editorial	(Peplow, 2013)
Investing in Graphene	Market Report by Cientifica	http://www.cientifica.com/wp-content/uploads/downloads/2013/07/Investing-in-Graphene.pdf

Case Closed: Graphene is the Next Carbon Nanotube	Blog entry by Lux Research (consultancy)	http://blog.luxresearchinc.com/blog/2015/07/case-closed-graphene-is-the-next-carbon-nanotube/
The rise of graphene	Review paper	(Geim & Novoselov, 2007)
Nobel Lecture: random walk to graphene	Nobel Lecture by Andre Geim	(Geim, 2011)
Moving Towards a graphene world	Editorial	(Van Noorden, 2006)
Roll-to-roll production of 30-inch graphene films for transparent electrodes	Research paper	(Bae et al., 2010)
Graphene: Near-term Opportunities and Long-term Ambitions	Market Report Brochure	http://blogs.cimav.edu.mx/oscar.solis/data/files/Nanotecnolog%C3%ADa/Grafeno.pdf
The Godfather of Graphene	Interview in The Economist	(Whittel, 2014)
Graphene producer's IPO oversubscribed	News Financial Times	(Tighe, 2013)
IDTechEx forecasts a $100 million graphene market in 2018	News on market report Release	https://www.cambridgenetwork.co.uk/news/idtechex-forecasts-a-100-million-graphene-market-in-2018/
Against the Wind - Is Gild Off the Graphene Lily?	Opinion article in AzoNano	http://www.azom.com/article.aspx?ArticleID=10003
Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems	Paper - roadmap	(Ferrari et al., 2014)
Two-dimensional gas of massless Dirac fermions in graphene	Research Paper	(Novoselov et al., 2005)
Graphene – what's next after the hype?	Blog entry	http://www.idtechex.com/research/articles/graphene-what-next-after-the-hype-00005454.asp
Graphene booms in factories but lacks a killer app	Editorial	(Peplow, 2015)

GRAPHENE-CA WP6 Project Management of the CA project. Deliverable 6.3 "Publishable flagship proposal report"	Report for Flagship application	http://ec.europa.eu/research/participants/portal/doc/call/h2020/h2020-fetflag-2014/1595109-6pilots-graphene-publicreport_en.pdf
Carbon nanomaterial commercialization: Lessons for graphene from carbon nanotubes	Review paper	(Arthur et al., 2012)
A roadmap for graphene	Review paper, roadmap	(Novoselov et al., 2012)
About the Graphene Flagship	Website	http://graphene-flagship.eu/?page_id=5
Science and Engineering Beyond Moore's Law	Review paper	(Cavin, Lugli, & Zhirnov, 2012)
FET Flagship: Evaluation Process	Report	http://cordis.europa.eu/fp7/ict/programme/fet/flagship/doc/conf-nov2011-06_en.pdf
Idea. From Nanolab to reality	Presentation	http://cordis.europa.eu/fp7/ict/programme/fet/flagship/doc/flagship-ws-june10-26-jari-kinaret_en.pdf

D.2. 3D printing

Name	**Type**	**Reference (URL)**
3D Printing and Humanity's First Imperfect Replicator	Review Paper	(Bowyer, 2014)
VoxelFab's Joris Peels talks gaps between potential and reality of 3D printing	Video of conference presentation	https://www.youtube.com/watch?v=ljamzOHEBUs
A Promise is a Promise — Ultimaker Releases Source Files for its 2nd Gen 3D Printer	Blog entry	http://3dprintingindustry.com/2014/03/31/promise-promise-ultimaker-releases-source-files-2nd-gen-3d-printer/
Crowdfunding & The Low-Cost Desktop 3D Printer: A Suicidal Race To The Bottom?	Blog entry	http://3dprintingindustry.com/2014/08/01/crowdfunding-low-cost-desktop-3d-printer-suicidal-race-bottom/

Additive Manufacturing and 3D printing	Article	(Hague & Reeves, 2013)
The Econolyst's Dr Phil Reeves on embedding 3D Printing into the Supply Chain at TCT Show 2014	Video of conference presentation	https://www.youtube.com/watch?v= P1Tt4mDTS3k
An Insider's view of the myths and thruths of the 3D printing 'phenomenon'	Magazine article	http://www.wired.com/2013/05/an-insiders-view-of-the-hype-and-realities-of-3-d-printing
3D Printing Drives Digitization Further Into Products, Processes, And Delivery Models: A 3D Printing Primer For CIOs	Market report	https://www.forrester.com/3D+Printing+Drives+Digitization+Further+Into+Products+Processes+And+Delivery+Models/fulltext/-/E-RES104904
Formide – New Cloud-based 3D Printing Platform to Launch in November by Printr	Blog entry	http://3dprint.com/18377/formide-3d-print-platform/
Tracking Global Growth in Industrial-Scale Additive Manufacturing	Review paper	(Wohlers, 2014)
Introducing the YouMagine Team: Erik de Bruijn	Blog entry	https://blog.youmagine.com/2014/09/introducing-the-youmagine-team-erik-de-bruijn/
YouMagine 3DPL	License draft	https://medium.com/@jorispeels/youmagine-3dpl-c11fce097ae
3DPL released: an Open Source License for 3D Printed Things	Blog entry	https://blog.youmagine.com/2015/03/3dpl-released-an-open-source-license-for-3d-printed-things/
Ultimaker 2 Source Files	Blog entry	https://www.youmagine.com/designs/ultimaker-2-source-files
Celebrating 10,000 Printers!!!	Blog entry	https://www.3dhubs.com/talk/thread/celebrating-10000-printers
Exclusive Interview with Briam Garret, Co-Founder of 3D Hubs	Interview	http://www.inside3dp.com/exclusive-interview-brian-garret-co-founder-3d-hubs/
A Promise is a Promise - Ultimaker	Forum	http: //forums.reprap.org/read.php?1,332823

On the viability of the open source development model for the design of physical objects. Lessons learned from the RepRap project	Thesis	http://thesis.erikdebruijn.nl/master/MScThesis-ErikDeBruijn-2010.pdf
Gartner's 2013 Hype Cycle for Emerging Technologies features Humans and Machines	Blog entry	http://www.3ders.org/articles/20130819-gartner-2013-hype-cycle-for-emerging-technologies-features-humans-and-machines.html
Nick Allen, Managing Director, 3DPRINTUK @ TCT Show + Personalize 2013	Video	https://www.youtube.com/watch?v=YOLXewe9hqA
Diginova: Innovation for Digital Fabrication	Presentation	(Slot, 2014)
The Self-replicating Rapid Prototyper-Manufacturing for the Masses	Conference paper	(Bowyer, 2007)

E. Annex: Sample questions for semi-structured interviews

Note: these are sample questions. In practice, the questionnaires varied in each case. Each questionnaire was composed of approximately 20 open questions. Sample questions are taken from different interviews, and thus they are not necessarily related.

E.1. Graphene

1. Can you tell me briefly how you got involved in graphene research?
2. Have the important areas of graphene research changed or expanded?
3. Have the envisioned application areas for graphene changed as well?
4. Does this change mean that new actors have come into the field?
5. Why did you think the flagship in graphene was selected?
6. What do you see as the major challenges for its success?
7. How has been the process of engaging industrial partners in the flagship?
8. There is now enormous attention being paid to graphene. How did this enormous attention come about, in papers, patents but also in the media?
9. I understand that one of the key steps in the flagship project is the development of a roadmap for graphene, how are you involved in that?
10. What were 'obvious' choices (for the roadmap), and which were topics of (strong) debate?
11. How is the graphene roadmap linked with the ITRS roadmap?
12. Do you know how it has been received by industry? Is it compatible with industries' / firms' own roadmaps?
13. What is the function of this roadmap for you?
14. What are the main challenges in bringing actual graphene applications to the market?
15. Can you tell me about the process of getting investors?
16. Graphene has been sometimes linked with CNT or other carbon materials. What does graphene actually inherit from CNT?
17. I understand that one, if not the most important steps to graphene commercialization is manufacturing. How is this challenge being address today in the field?
18. Do you perceive any attention to risk in nanomaterials for electronics, for example, in the case of occupational health or disposal of materials?
19. (If not) what do you think this lack of attention to risk stems from?

E.2. 3D printing

1. You got involved in the RepRap project quite early, so, can you tell me what drew your attention back then, and how was the process of getting involved?
2. And what does being a “maker” mean to you?
3. Has the governance structure of the RepRap community changed, or do you still keep the core values in this extended network?
4. What have been the tradeoffs of building a company and is it what you expected initially?
5. Is it a common practice among 3D printing companies to have these open workshops?
6. What is your idea of creating value?
7. You do a lot of community stuff, why is this important?
8. If the technology (Additive Manufacturing) is at least 20 years old, why is it that we were not able to anticipate its outcomes? Do you perceive that policy makers, or the government institutions in general, have had a late involvement with the technology? Why is it so?
9. What about the FabLab, open source movements that have had some degree of importance in the 3D printing area… are they, or do you expect them, to push for specific IP and liability schemes? What are their interests? And where do the negotiations take place?
10. You have stressed that 3D printing will really revolutionize the way we do things. Why do you say so? And what is to be expected?
11. Can you tell me what is so compelling about the idea of 3D printing contributing to the Third Industrial Revolution? Is this a vision, or is it happening already? How do you feel policy is becoming engaged with this idea?
12. How important is the vision of 3D printing called of “atoms to bit” ?
13. How important is the vision of “wealth without money”?
14. In one of your presentations, you mention the Gartner's hype cycle and also the predictions of IBM for the future of Digital Business. Can you tell me, why are these types of predictions relevant, and for whom? What makes them work as predictions?
15. What were the main challenges of the Kickstarter campaign you went through? What would you do differently if you would do it again?

Samenvatting

De ontwikkeling van nieuwe technologieën wordt aangestuurd door visies, beloftes en zorgen die samen een voorstelling geven van de mogelijkheden die opkomende technologieën kunnen bieden. Beloftes over nieuwe technologieën, zelf het resultaat van individuele en collectieve verbeelding, verspreiden zich als narratief door de samenleving, waarin nieuwe technologieën nieuwe werelden mogelijk maken, onze huidige en toekomstige problemen oplossen en/of ons enorme schandalen en catastrofes brengen. Dit soort verwachtingen, oscillerend tussen hoop en vrees, spelen een centrale rol in de vormgeving van de toekomst van technologie – en daarmee ook van de toekomst van de samenlevingen waarin ze zijn ingebed.

Dit onderzoek sluit aan bij een nieuw onderzoeksveld in STS, de Sociology of Expectations (Sociologie van Verwachtingen), dat voor een groot aantal opkomende technologieën de constitutieve rol van beloftes en zorgen onderzoekt in processen van technologische verandering. Ook in beleidskringen wordt het belang van het verbeelden van toekomstige mogelijkheden erkend. In beleidsvoering krijgen foresight (voorspellen, anticiperen, vooruitplannen) en toekomstgerichte instrumenten een steeds grotere rol toebedeeld. In dit proefschrift heb ik onderzocht hoe verwachtingen rondom technologie worden gecreëerd, in welke praktijken ze ontstaan en of dit er toe doet. Niet alle verwachtingen hebben eenzelfde effect in socio-technische ontwikkelingen. De condities waaronder specifieke verwachtingen 'performatief' worden, verschillen aanzienlijk, zodat niet elke verwachting uiteindelijk ook een 'actionable' of uitvoerbare socio-technische toekomst wordt. Mijn centrale onderzoeksvraag is daarom,

> Wat voor soort praktijken geven vorm aan de dynamiek van verwachtingen rondom opkomende technologieën en wat zijn de performatieve effecten van deze verwachtingen?

In deze context, omdat het centrale thema betreft hoe de toekomst van opkomende technologieën wordt voorgesteld en vorm krijgt in de praktijk, noem ik dit proefschrift "mindful anticipation" ("bedachtzame anticipatie"). Dit verwijst naar een benadering om de toekomst te bestuderen door zorgvuldig aandacht te besteden aan de huidige manieren om temporeel en ruimtelijk vorm te geven aan toekomstmogelijkheden. Ik heb praktijken van anticipatie die aan de basis staan van twee opkomende gebieden, grafeen en 3D-printen, bestudeerd en vergeleken. Ik heb onderzocht hoe deze praktijken de performatieve effecten van verwachtingen kunnen verklaren. Deze twee technologieën, die rond het midden van de jaren 2000 brede aandacht begonnen te krijgen, hebben een fase doorgemaakt waarin enthousiasme en overdreven beloften de boventoon voerden, ook wel aangeduid als hype. Ik onderzoek hoe deze twee hypes zijn geconstrueerd over verschillende sectoren, van de academische wereld tot beleidskringen en van start-ups tot de financiële sector. Ik richt me op lokale praktijken en hun globale effecten. Hiermee benader ik de dynamiek van verwachtingen niet slechts als het resultaat van lokaal gesitueerde praktijken, maar ook als een samengesteld fenomeen.

De bijdrage van deze thesis is drieledig: ten eerste heb ik een raamwerk ontwikkeld om nieuwe mogelijke (technologie) praktijken en hun effecten te bestuderen. Ten tweede heb ik dit raamwerk empirisch toegepast op twee technologische velden (grafeen en 3D-printen) en heb ik onderzocht hoe toekomstgerichte praktijken deze technologieën definiëren. Tenslotte reflecteer ik op de hoeveelheid aan methodologie-en, actoren, praktijken en contexten waarin de toekomst van een technologie wordt ontwikkeld. Hierbij reflecteer ik op wat het betekent om op een verantwoordelijke en bedachtzame manier te anticiperen.

De thesis bestaat uit zeven hoofdstukken. **Hoofdstuk 2** introduceert en ontwikkelt een raamwerk om 'anticipatie' als een 'praktijk' te conceptualiseren. Ik ontwikkel hier het idee van anticipatie praktijken om deze vervolgens die praktijken te bestuderen waarin de toekomst wordt vormgegeven, expliciet en impliciet, van forecast-studies tot aan de ontwikkeling van prototypes. Ik richt me hierbij op hoe deze praktijken, samen en in relatie tot elkaar, bijdragen aan het ontstaan en de werking van opkomende technologiegebieden. In **hoofdstuk 3** introduceer ik de methodologie die ik toepas om deze praktijken te bestuderen, waarbij ik me baseer op een aantal traditionele en digitale etnografische methoden om de ontwikkeling van verschillende praktijken in hun context te beschrijven in relatie tot het technologische veld van onderzoek. Ik introduceer in detail de twee casussen en de criteria en overwegingen bij de keuze voor deze twee casussen.

De drie empirische hoofdstukken behandelen verschillende deelaspecten van de hoofdvraag. **Hoofdstuk 4** beschrijft in detail de opkomst van grafeen vanuit het perspectief van de verwachtingen bij dit veld. Ik laat zien hoe aan de ene kant lokale anticipatie praktijken in gang worden gezet door bestaande technologische 'regimes' en, aan de andere kant, hoe deze praktijken een globale innovatiedynamiek bewerkstelligen en veranderen. Het hoofdstuk laat zien hoe anticipatie praktijken, specifiek voor bepaalde domeinen zoals wetenschappelijke publicaties, wetenschapsbeleid of de commerciële markt, in gang worden gezet en hoe deze met elkaar verbonden raken. Het hoofdstuk laat zien dat sommige anticipatie praktijken specifiek zijn voor bepaalde gebieden; deze praktijken produceren op hun beurt typisch gemeenschappelijke verwachtingen (ingebed in conversaties, rapporten, publicaties, diagrammen etc.) die kunnen worden vertaald naar andere gebieden, alwaar deze verwachtingen door andere actoren worden opgepakt. Het laat zien dat de processen van het anticiperen op en het vormen van een innovatiegebied, afhankelijk is van een gradueel ontvouwende 'assemblage' van praktijken, actoren en verwachtingen die zich door verschillende gebieden bewegen, die daarbij een bepaalde mate van legitimiteit en stabiliteit vergaren.

Hoofdstuk 5 onderzoekt de 'socio-materiële' praktijken waarin anticipatie plaatsvindt in relatie tot het veld van 3D-printen. Meer specifiek richt het hoofdstuk zich op de relatie tussen praktijken, de contexten waarin ze zijn ingebed en bijbehorende logica's. Anticipatie vindt niet alleen plaats in praktijken die expliciet gericht zijn op het verkennen van de toekomst, zoals roadmaps, of foresight studies, maar is ook onderdeel van diverse innovatiepraktijken, waarin innovatie-actoren betrokken zijn bij de productie van de technologie: het ontwikkelen van prototypes, het vormen van netwerken, fondswerving etc. Deze praktijken vormen en worden gevormd door verwachtingen; ze zijn geïnformeerd door bestaande beloften en zorgen en worden ook strategisch ingezet om deze verwachtingen in stand te houden of te veranderen. Er zijn twee logica's die de anticiperende praktijken in dit hoofdstuk sturen: 'techno-wetenschappelijk' en 'open source'. Een techno-wetenschappelijke logica wordt gekarakteriseerd door grote beloften en een gevoel van urgentie. Een open source logica wordt gekarakteriseerd door herhaald experimenteren. In mijn empirische observaties zie ik dat in veel gevallen een combinatie van logica's sturend zijn in de praktijken. Toch is het onderscheiden van logica's belangrijk. De mate waarin een specifieke praktijk wordt beïnvloed door een of andere logica heeft invloed op de wijze waarop anticipatie plaatsvindt. Hierdoor worden zowel keuzes met betrekking tot de toekomst van een technologie gevormd (pad-afhankelijkheid) als ook de mate van reflectie op deze verwachtingen.

Hoofdstuk 6 richt zich op technologie consultants als 'belofte-actoren' en hoe zij het 'hype-cycle' diagram inzetten. Het laat zien dat deze consultants een bepaald soort kennis over hypes produceren, gebaseerd op hun ervaring en interacties met andere actoren in het veld. Ik betoog dat kennis over hypes ontstaat in coproductie met de hypes zelf en dat dit soort kennis performatief is – net zoals bij verwachtingen. Om hypes te begrijpen is het niet voldoende om ze alleen maar aan te wijzen. Hypes moeten ook ondersteund worden met een theorie die een bepaalde inschatting onderbouwd. Daarom hebben consultants methoden nodig om de robuustheid van de gerelateerde verwachtingen te toetsen. Zodra kennis collectief wordt, verandert en vormt het, het betreffende veld. Dit proces wordt bemiddeld door praktijken die specifiek zijn voor consultants. Een van de effecten van het werk door consultants, is de verspreiding van specifieke vormen van anticiperende coördinatie door het gehele technologische veld – dat wil zeggen: consultants bieden niet alleen kennis over de toekomst aan, maar verspreiden ook actief hun specifieke wijze van anticiperen op de toekomst naar andere actoren, waarmee ze hun anticiperende praktijken 'koloniseren'. Aan de ene kant positioneren consultants zichzelf tegenover de dynamiek van beloften en hypes, waarbij ze zich een experts status proberen aan te meten aan de hand van "realistische" verwachtingen en kritische toetsing. Aan de andere kant uiten ze actief een enthousiasme voor een specifiek technologisch veld. Door deze handelwijze vormen consultants de markt voor nieuwe technologieën, maar creëren ze ook en niche voor zichzelf als onmisbare actoren in die markt.

Hoofdstuk 7 is het laatste en concluderende hoofdstuk. Hierin presenteer ik een overzicht van mijn onderzoeksbevindingen in relatie tot de centrale onderzoeksvraag en bespreek ik de relatie tussen anticipatie praktijken en hun performativiteit. Ik laat zien hoe deze aanpak het mogelijk maakt om anticipatie te begrijpen als een doorgaand proces en onderzoek ik de praktische implicaties van deze bevindingen. Ik benoem expliciet de verbindingen tussen de verschillende hoofdstukken en hoe deze bijdragen aan de literatuur over de Sociology of Expectations, Anticipation en Anticipatory Governance en aan het begrijpen van de toekomst in sociale theorieën in het algemeen.

Samengevat vestigt dit proefschrift, dat ik de titel "Mindful Anticipation" heb gegeven, de aandacht op praktijken waarmee collectieve verwachtingen gecirculeerd worden en daarmee de toekomst vormgeven waar ze zelf naar verwijzen. Deze aanpak is een uitbreiding van het huidige onderzoek in de Sociology of Expectations, door te benadrukken dat de manier waarop verwachtingen worden geschapen in verschillende contexten hun performativiteit beïnvloedt. In algemene zin verwijst de "mindfulness" van anticipatie naar het gedetailleerd aandacht hebben voor de wijzen waarop de toekomst wordt gemaakt in het heden, zoals dit gebeurd in techno-wetenschappelijke praktijken, met gevolgen voor zowel het heden als de toekomst. Mijn stelling is dat als we dit perspectief in acht nemen – als we ons bewust (mindful) zijn van hoe collecteive praktijken gevormd worden door de toekomst – het ook mogelijk wordt om de wijze waarop we de toekomst vormgeven te bevragen en te veranderen.

New technologies exist first only as semi-magic speculations of possible and potential futures. The construction of these futures lies in practices through which the relations between technology and society are embodied and shaped. Often, these practices remain unnoticed - mindless - overviewing the key decisions that are made in the present in the name of the future. This PhD thesis explores how these "anticipatory practices" constitute the futures of two emerging technologies: graphene and 3D printing. Working from a Science and Technology Studies and Governance perspective, the author proposes a framework to think - mindfully - how collective and implicit decisions made in the present matter for our shared future.

Carla Alvial Palavicino conducted this research at the Science, Technology and Policy Studies Department (STePS), University of Twnete, NL.