FET_TRACES

Tracing impacts of the FET programme

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About FET_TRACES

FET_TRACES is a research project for the European Commission which analyses and measures the impacts of the research funding scheme “Future and Emerging Technologies Open” (FET Open and FET Proactive). Within the European research funding landscape, the FET scheme acts as a pathfinder for new ideas and themes for long-term research in the area of information and communication technologies and beyond. Its mission is to promote high risk research, offset by potential breakthrough with high technological or societal impact (see http://cordis.europa.eu/fp7/ict/fet-open/home_en.html).

In the FET_TRACES project we will investigate and measure direct and indirect impacts of these two schemes on the science and technology landscape and its perception by individual researchers who are potential proposers for FET Open and FET Proactive projects. Results from innovation research will be used to develop a targeted indicator set covering central aspects of the FET mission (novelty, trans-disciplinarity, innovation-ecosystem). For the data collection we use sophisticated impact assessment methods like bibliometrics, patent analysis and online surveys. In addition to the impact assessment we will analyze selected breakthrough-projects to find out about necessary components for “breakthrough”-research. The study will also include insights from FET-like funders on national levels in Europe.

Terms of use

This document was developed within the FET_TRACES project (see www.fet-traces.eu), funded by the European Commission within Horizon 2020, by a consortium consisting of two partners, the Fraunhofer ISI in Karlsruhe, Germany (coordinator) and AIT in Vienna, Austria.

Document history

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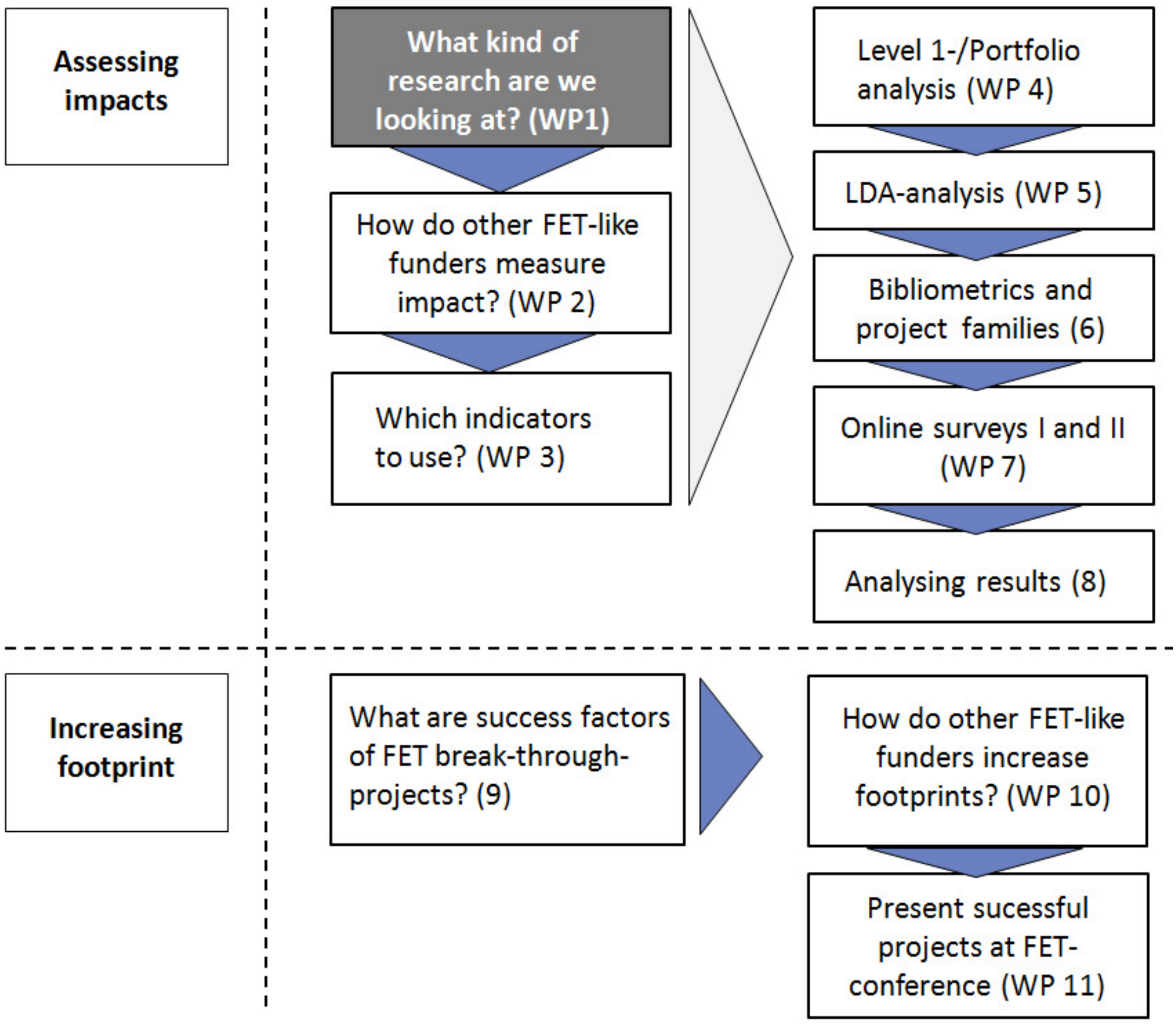
1.0	December 22, 2015	

Contents

Background

Objectives	Location	Output
Develop a scientifically sound conceptual framework for the impact assessment, taking into account the special type of FET-research and recent insights from science research.	WP 1	Insights from science research on the specific characteristics and requirements of FET-like research and suggestions on how to trace impacts of this special kind of research.



1 Mission of the FET programme

For the impact analysis of the FET programme, the overall mission of the programme is the natural starting point. The key questions are: What are the goals of the programme? What does it try to achieve? And: Who are the addressees of the programme and what is the intervention logic? Because the FET programme is a very specific and in some ways "unusual" programme within the European research funding landscape, a careful description of its aims and intentions is necessary.

In the following, we will characterize the FET programme using pieces of information provided by the FET unit on its website[1] and from diverse strategy papers, the lastest being the report from the FET Advisory Group "The Future of FET: A possible nucleus for the European Innovation Council" of September 2015 (The FET Advisory Group 2015).

The Future and Emerging Technologies (FET) programme of the European Commission consists of three schemes or complimentary lines of action, which – according to its self-description – have the mission "to turn Europe's excellent science base into a competitive advantage"[2]. The description of FET continues: "FET actions are expected to initiate radically new lines of technology through unexplored collaborations between advanced multidisciplinary science and cutting-edge engineering." On its website, the FET Unit describes its three schemes as follows:

- FET Open funds projects on new ideas for radically new future technologies, at an early stage when there are few researchers working on a project topic. This can involve a wide range of new technological possibilities, inspired by cutting-edge science, unconventional collaborations or new research and innovation practices.

In an earlier version of its self-description, FET Open was described as "a 'roots-up' approach for exploring promising visionary ideas that can contribute to challenges of long term importance for Europe. The scheme stimulates non-conventional targeted exploratory research cutting across all disciplines and acts as a harbour for exploring and nurturing new research trends and helping them mature in emerging research

1 https://ec.europa.eu/programmes/horizon2020/en/h2020-section/future-and-emerging-technologies

2 This and the following quotes are taken from the FET-website at: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/future-and-emerging-technologies

communities".[3]

- FET Proactive nurtures emerging themes, seeking to establish a critical mass of European researchers in a number of promising exploratory research topics. This supports areas that are not yet ready for inclusion in industry research roadmaps, with the aim of building up and structuring new interdisciplinary research communities.

In an earlier version of its self-description, FET Proactive was described as "a 'top-down' approach fostering novel non-conventional approaches and foundational research in selected themes in response to emerging societal and industrial needs. The scheme supports initial developments on long-term research and technological innovation, and helps related research communities to develop and mature".[4]

- FET Flagships are 1-billion, 10-years initiatives where hundreds of excellent European researchers unite forces to focus on solving an ambitious scientific and technological challenge, like understanding the Human Brain or developing the new materials of the future, such as Graphene.

Our impact assessment will extend to FET Open and FET Proactive but exclude the FET Flagship scheme because the two current Flagship projects have started just recently (2014) and will run until the year 2024. Thus, impacts have to be monitored and measured in a different way than FET Open and FET Proactive projects. And in fact there are specific impact assessment activities going on in the context of implementing the FET Flagship projects.[5]

In a presentation of the FET programme, Ales Fiala, the Head of Unit of C2 at DG Connect uses the words "incubator" and "pathfinder" for new ideas and themes for long-term research to characterize its special role within the European research funding landscape.[6]

Underlying the FET mission is the purpose to turn Europe's excellent science base into a competitive advantage by uncovering radically new technological possibilities. The intentions of the programme makers are to "help Europe to grasp leadership early on in

3 See the archived Website at: http://cordis.europa.eu/fp7/ict/programme/fet_en.html

4 See above.

5 See for example the results of the workshop "The FET Flagship model, key policy and implementation issues", April 29, 2014 at http://ec.europa.eu/digital-agenda/en/news/conclusions-consultation-workshop-fet-flagship-model-key-policy-implementation-issues.

6 See presentation of the FET Unit at the ICT 2013-event in Vilnius at: http://ec.europa.eu/digital-agenda/events/cf/ict2013/item-display.cfm?id=11650.

new and emerging technology areas that promise to renew the basis for European competitiveness and growth and that will make a difference for society in the decades to come. (…) FET actions will help to create in Europe a fertile ground for responsible and dynamic multi-disciplinary collaborations on future and emerging technologies and for kick-starting new European research and innovation eco-systems around them”.[7]

An illustrative picture for the specific mission of the FET programme was given at the FET-Open CSA Infoday in May 2014: It was said that the FET programme intends to enhance the “jump capacity” of European research. This picture refers to the notion that there is a gap between excellent (academic) science on one side and science-based technology development on the other. FET in this picture shall help researchers and engineers to jump over this gap and turn science into technology.[8]

Both FET schemes analysed here share a set of characteristics, which are summarized in table 1.

Table 1: Key elements of FET´s mission

<table>
<tr><th>FET scheme</th><th>Key characteristics</th></tr>
<tr><td>FET Open (bottom-up)</td><td rowspan="2">visionary, high-risk, foundational, collaborative, across disciplines, long-term, technological innovation</td></tr>
<tr><td>FET Proactive (top-down)</td></tr>
</table>

Source: Based on van de Velde (2014)

Another summary of FET´s mission given in the context of the FET-Open CSA Infoday adapted from the Horizon 2020 programme description is: “[The] Future and Emerging Technologies [programme] shall support collaborative research in order to extend Europe´s capacity for advanced and paradigm-changing innovation. It shall foster scientific collaboration across disciplines on radically new, high-risk ideas and accelerate development of the most promising emerging areas of science and technology as well as the Union-wide structuring of the corresponding scientific communities.”[9]

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7 See above.

8 See Van de Velde, Walter (2014): FET-Open CSA topic Work Programme 2014-2015 in H2020. Presentation held at the FET CSA Info Day, 16th of May 2014, Brussels. Documentation online at: http://ec.europa.eu/digital-agenda/en/news/fet-infoday-coordination-and-support-activities-call-0).

9 See above

Within the European research funding landscape, the FET programme is mainly positioned against the European Research Council (ERC) and the Marie Skłodowska-Curie actions which have their own funding rationales. Table 2 shows that compared to these, the FET programme has a smaller budget.

Table 2: Position of FET in the Excellent Science pillar in Horizon 2020

Excellent Science pillar in H2020	
	Budget in billion Euros
European Research Council (ERC)	13
Marie Skłodowska-Curie actions	6,2
Future and Emerging Technologies (FET)	**2,7**
Research infrastructure programme	2,5

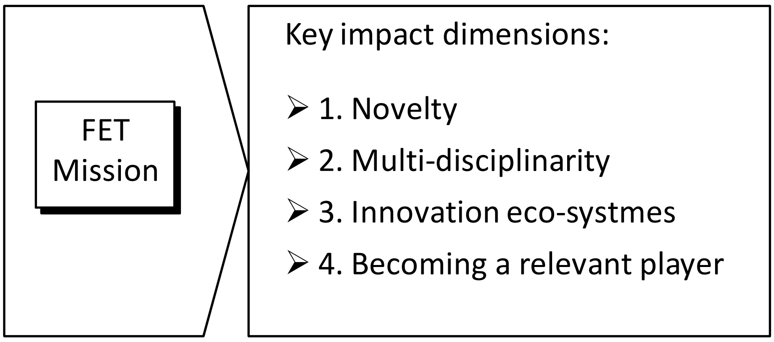
Source: European Commission (2013)

However, compared to the past framework programmes, FET has now become wider in the range of scientific disciplines eligible to apply for projects. Not only ICT and neighbouring research areas now have access to FET funding but all fields of science, according to the current Work Programme (European Commission 2013a). And FET has also become significantly bigger in terms of overall budget size in H2020. Thus, the ambitions of the programme makers and administrators have naturally been growing. It is their aim to install FET as a relevant and renowned actor in the European science and technology funding landscape. This includes that in the future, FET wants to become better known in the scientific community. Researchers and engineers shall know more about FET and shall not only think of the ERC or Marie Skłodowska-Curie actions when looking for funding for novel ideas and concepts in Europe.

2 Dimensions of the impact assessment

According to the presentations of the FET programme and the different sources consulted, the mission of FET consists of four main dimensions - which are at the same time the key dimensions for the impact analysis. Figure 1 shows these dimensions in an overview.

Figure 1: Key dimensions of the FET programme and its key impact dimensions



In order to condense the diverse goals which make up the uniqueness of the FET programme, the following allocations of mission keywords resp. programme values can be made:

1. Novelty: At the centre of FET are novel ideas, concepts, and approaches which may lead to radical new technologies. The keywords in the mission statement to characterize this aspect are “visionary”, “foundational”, “long-term” and “technological innovation”.

2. Multi-disciplinarity: Multi-discipinary approaches and collaborations across disciplines are the second key dimension of projects funded within the FET programme. This includes the claim that not only neighbouring disciplines or research fields alredy closely linked together (narrow interdisciplinarity) are supported, but that disciplines not related to each other at first sight may collaborate in FET projects (wide interdisciplinarity). The keywords in the mission statement to characterize this aspect are “collaborative” and “across disciplines”.

3. Innovation eco-systems: FET-projects shall start new economic activities based on the new technology or concept developed in the project. Apart from the scientific uptake, this includes industrial activites of any kind (company R&D, spin-offs, patent applications, etc.). The keywords in the mission statement to characterize this aspect are “technological innovation” and “visionary” as well as “SME-involvement”, and “technology focus”.

4 Becoming a relevant player in the funding landscape: This dimension is not directly related to the actual research being supported by the programme. Yet, it is an explicit goal of the FET Unit of the European Commission and reflects the conviction of the programme makers that this specific kind of research funding will yield exceptional results. Thus, the FET programme shall take a more prominent spot within the European funding landscape.

3 Characterizing FET research from an innovation and science research perspective

As indicated in the FET_TRACES project proposal in the section “Conceptual framework: What impacts can be expected from FET-like research?” (p. 12-17), it is important to describe the specific characteristics of FET research in order to derive adequate impact indicators. FET research is research in complex science-based technologies in the early stages of their development. This kind of research follows specific patterns which have to be reflected in the conceptual framework for the impact assessment accordingly. Thus, in the following theoretical reasoning we will give a general characterization of FET-like research according to the current state of research literature and we will especially point to the relevance of diffusion aspects of radically new concepts in the scientific and technological communities (innovation eco-systems).

In the context of the FET- programme, we look at activities in the so called “oriented basic research”, according to the official labeling of the Frascati manual. Donald Stokes (1997) called this type of research “use-inspired basic research” which Louis Pasteur has become famous for. Stoke describes two other types of research in his book “Pasteur´s Quadrant”: Pure basic research for which Bohr is an example of and pure applied research for which Edison is an example of. “Use-inspired basic research” is basic research from which it can be expected that findings of practical use might come out (see figure 2).

Figure 2: Pasteur’s Quadrant according to Stokes (1997)

Applied and Basic research

Quest for fundamental understanding?	**Yes**	Pure basic research (**Bohr**)	Use-inspired basic research (**Pasteur**)
	No	–	Pure applied research (**Edison**)
		No	**Yes**
		Considerations of use?	

Source: Wikipedia “Pasteur´s quadrant”

This specific orientation means for FET that research funding is not distributed evenly in a watering-can-principle, that the funded research is not totally free, but that the funded research in the long term should have a realistic application potential.

The different types of research are linked to different types of researchers. In the case of oriented basic research, the researchers conduct advanced basic research, but not only for satisfying his or her own curiosity, but with a steady awareness for potential applications of the research results.

As to FET, the application refers to technology.[10] These researchers work at the borderline between science and technology. They may present their findings as breakthroughs at a scientific conference and, in parallel, as new promising technological devices at an enterprise.

Although FET is designed to transfer scientific discoveries into technological applications as soon as possible, there are certain timing-aspects to be considered in this context. It is well known in science research that the relevance of important scientific breakthroughs is not necessarily recognized directly after their first publication (Atkins 2003 or van Raan 2004). As they are radically new, they do not fit into the mainstream discourse and therefore are often overlooked for a long time. As a famous example, the foundations of genetics and heredity published by Mendel in 1865 were ignored for many decades. In bibliometrics, there is even a relevant discourse about these “sleeping beauties” (Cressey 2015). The challenge of getting recognised and disseminated and not getting forgotten, is also relevant for FET projects. Strategies of getting attention and promoting research results at an early stage thus get into the focus.

Various studies in science research have shown that it is not sufficient to discover or develop completely new scientific concepts which are described as scientific revolutions by Kuhn (1962). In addition, it is necessary to actively disseminate the new concept in the scientific community and to build up networks with likeminded colleagues, thus to enact the new concept (e.g., Griffins/Mullins 1974 or Bourdieu 1975). In the context of FET, research results not only need to be communicated exclusively to the academic community, but also to enterprises, e.g. to company R&D.

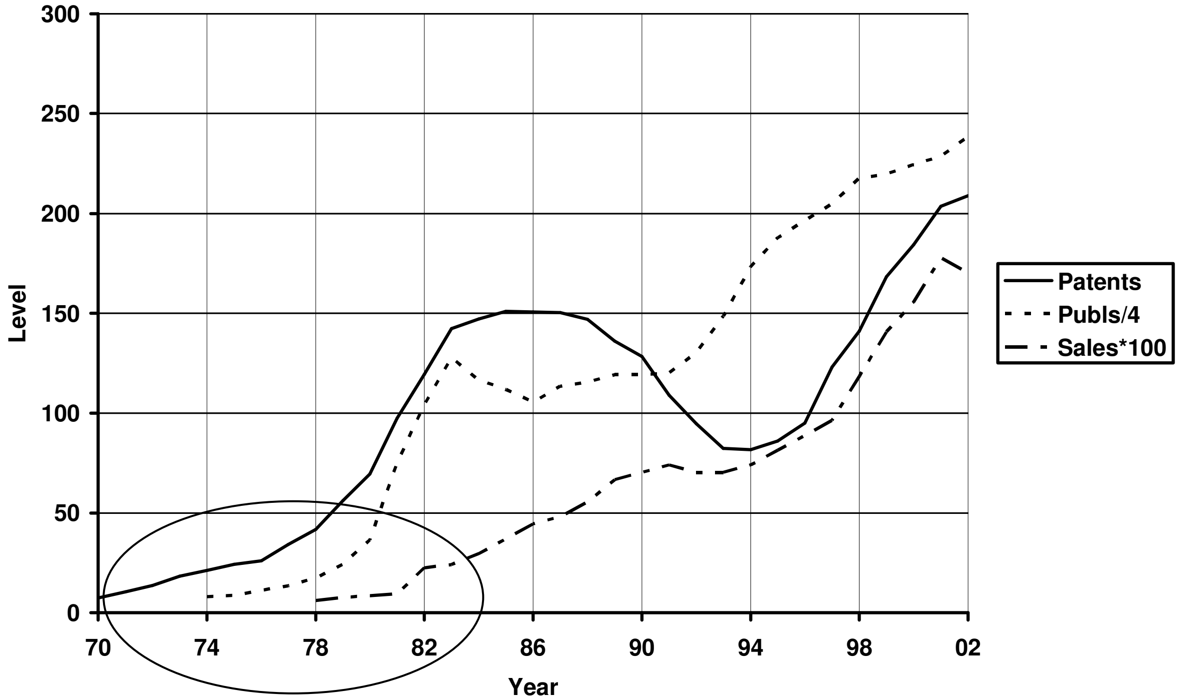
The FET programme aims at science-based technologies which are complex technologies substantially based on results of scientific research. The typical development of such technologies was systematically investigated by Ulrich Schmoch in his 2007-

10 Not all scientific research like in philosophy, sociology, history or similar fields in social sciences and humanities is designated for technological outputs.

article in *Research Policy* titled "Double-boom cycles and the comeback of science-push and market-pull" (Schmoch 2007) and by Ulrich Schmoch and Axel Thielmann in their 2012-contribution to the journal *Research Evaluation* "Cyclical long-term development of complex technologies. Premature expectations in nanotechnology?" (Schmoch and Thielmann 2012). The main results of these works are:

- The development of a radically new concept into a broadly accepted technology generally takes a long period of 20 or even more years (see figure 3).
- There is not a simple sequence of research types like in the science-push model, but basic and applied research are conducted in parallel even in early stages. Thus, with a short delay after the first publication of the concept in journals, conference presentations or patent application, patents and scientific publications display a parallel progression (see the patent and publication lines in figure 3).
- In many cases, the patent activities decrease after about 10 years, but in the long run the concept proves to be valid and the patent activities re-increase. Schmoch (2007) calls this typical development a "double-boom cycle".

Figure 3: Development of robotics as reflected in patent applications, publications and sales



Source: Schmoch 2007, p. 1006

These typical features of the development of science-based technologies may be illustrated by the example of patent applications, publications and turn-over linked to robotics. The patent applications and publications referring to this field start at a low level almost in parallel in early stages of its development.[11] This reflects that in technology-oriented science fields the communication between academic and industrial researchers via telephone calls, informal meetings, E-mails, workshops etc. is generally quite close. This phenomenon was labeled as “technological community” by Rappa and Debackere (1992). The first peak of the patent activities is achieved after about 10 to 15 years. Then the patent activities decrease, as in the perspective of industrial managers the achieved sales in relation to the investment in research are still too low. Then – after the solution of crucial problems – the patent activities increase again and the level of sales steadily grows. This real breakthrough takes place about 20 years after the first activities in the field.

This development for robotics can be observed in various other science-based technologies such as immobilized enzymes, electrically conducting polymers, artificial interferons, or polymerisation catalysts, as Schmoch (2007) has shown. This typical development is not a strict law, but applies to the majority of science-based technologies. FET projects could be allocated to the early stages of such a development marked in figure 3 by a circle. Thus, the activities on the science level (publications) and on the technology level (patents) will be moderate, and relevant sales cannot be observed yet. It is important to be aware of these long cycles of development to avoid unrealistic expectations of substantial impact in early stages. The impact indicators to be used in this project have to reflect this time-delay effect.

If a scientific concept with technological implications is radically new, this is not a guarantee for a relevant success in the marketplace. For instance, academic research often provides interesting ideas for new complex measuring devices which do not find broader interest from manufacturers or other actors in the commercial area. A good way to look at FET projects therefore is to see their situation similar to that of start-up enterprises and to borrow from risk-funding experiences. In risk funding, the basic expectation is that only 1 business concept out of 10 is really successful, but the profit of this special enterprise largely outperforms the losses of the other 9 start-ups (see, e. g., Dietz and Rogers 2012). The scientific review of FET proposals may reduce the risk of failure, but there are many uncertainties in the academic area and in the marketplace, so that many failures are still probable. In consequence, it can be considered as a suc-

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11 Meanwhile robotics is a large economic area with steadily new elements such as service robotics. Patents and publications still run in parallel.

cess, if about 10 percent of the supported FET projects lead to a successful proof of concept or a technology with substantial economic impact in the long run.

In addition to recognizing time-lags and realistic success rates for technological breakthroughs, science research has pointed to the importance of social activities and communication in the process of spreading new scientific concepts (Stokes 1996, Griffins/Mullins 1974, Bourdieu 1975, Atkins 2003, van Raan 2004, Kuhn 1962 or Schmoch 2007, 2012). As mentioned above, it is generally not enough to have invented a new device, concept or method. To spread the new concept, specific follow-up activities are crucial to initiate a technological community around the new concept, idea or technology. These technology-oriented follow-up activities are crucial for the success of new concepts and they shall take place already in the short term, e.g. within the first five years after the start of a FET project. These follow-up activities may be publications in technology-oriented journals or with co-authors from industry, patent applications, presentations at conferences with mixed academic and industrial audiences, spin-offs, industry contacts, researchers exchange with industrial R&D facilities, etc. These examples emphasize the need to team up with other actors from industry in order to spread the idea in the wider technology developing community.

Updates

In order to update and complement our conceptual framework on the issues of cyclical developments and long-term perspectives of new S&T concepts, we carried out a bibliometric research to identify recent publications on these issues. It turned out that the insights of Schmoch (2007) and Schmoch and Thielmann (2012) have not been further elaborated by other authors. However, the search brought to light a study by Rotolo et al. (2015), which is highly relevant for our work and which will be presented here in more detail. The work of science policy researchers Daniele Rotolo, Diana Hicks and Ben R. Martin appeared in July 2015 in *Research Policy* with the title “What Is an Emerging Technology?” (Rotolo et al. 2015). Their main research question is, what classifies a technology as “emergent” and how can can the respective theoretical concepts be operationalized.

Rotolo et al. (2015) state that in the last years, emerging technologies increasingly attract attention. In particular since 2005, a growing number of articles on this topic can be observed. However, the mass of more than 500 publications per year offers a variety of different definitions and operationalisations of emerging technologies and against this background, the authors try to systematise the different approaches. For that matter they identified twelve core papers on innovation research defining emerging technology (Martin 1995, Day and Schoemaker 2000, Porter et al. 2002, Corrocher et al.

2003, Hung and Chu 2006, Boon and Moors 2008, Srinivasan 2008, Cozzens et al. 2010, Stahl 2011, Alexander et al. 2012, Halaweh 2013 and Small et al. 2014). A selection of definitions from Rotolo et al. 2015 is shown in table 3.

Table 3: Definitions of emerging technologies

Study	**Domain**	**Definition**
Martin (1995)	S&T policy	"A ´generic emerging technology´ is defined (...) as a technology the exploitation of which will yield benefits for a wide range of sectors of the economy and/or society" (p. 165)
Day and Schoemaker (2000)	Management	"(...) emerging technologies as science-based innovation that have the potential to create a new industry or transform an existing one. They include discontinuous innovations derived from radical innovations (...) as well as more evolutionary technologies formed by the convergence of previously separate research streams." (p. 30)
Porter et al. (202)	S&T policy	"Emerging technologies are defined (...) as those that could exert much enhanced economic influence in the coming (roughly) 15-year horizon." (p. 189)
Corrocher et al. (2003)	Evolutionary economics	"The emergence of new technologies is conceptualised (...) as an evolutionary process of technical, institutional and social change, which occurs simultaneously at three levels: the level of the individual firms or research laboratories, the level of social and institutional context, and the level of nature and evolution of knowledge and the related technological regime." (p. 4)
Cozzens et al. (2010)	S&T policy	"Emerging technology – a technology that shows high potential but hasn´t demonstrated its value or settled down into any kind of consensus" (p. 364). "The concepts reflected in the definitions of emerging technologies, however, can be summarised four-fold as follows: (1) fast recent growth; (2) in the process of transition and/ or change; (3) market

		or economic potential that is not exploited fully yet; (4) increasingly science-based." (p. 365-366)
Small et al. (2014)	Sciento-metrics	"(...) there is nearly universal agreement on two properties associated with emergence – novelty (or newness) and growth." (p. 2)

Source: Selection from Rotolo et al. 2015, p. 9

Analysing all twelve papers in detail, Rotolo et al. (2015) found five attributes of emerging technology to be widely agreed upon:

1) Radical novelty
2) Relatively fast growth
3) Coherence
4) Prominent impact
5) Uncertainty and ambiguity

The systematic compilation of attributes proves to be very helpful for understanding the features of emerging technologies. The targets of the Future and Emerging Technologies program (FET) of the European Commission, however, in some instances differ from the attributes of the broad analysis of Rotolo et al. (2015). We discuss the specific differences in the following.

As to 'radical novelty', the close reference to standard definitions of innovation research is obvious which also includes the discussion of differences between discontinuous, revolutionary or disruptive innovations in contrast to 'incremental innovations'. An interesting aspect is that Rotolo et al. include "applying an existing technology from one domain to another domain" (ibid.: 1831). The authors cite an example of wireless communication technology:

"This technology was created for laboratory purposes, and specically for the measurement of electromagnetic waves. Yet, it found numerous subsequent applications. Wireless communication technology first enabled communication with locations (e.g. lighthouses) otherwise not reachable with wired telegraphy. Then, applications expanded to the transmission of voice (radiotelephony and broadcasting), and, more recently, to data transmission (Wi-Fi). With each shift, wireless communication technology appeared radically novel in its new domain of application, although the technology itself had existed since the early laboratory and telegraphy applications" (Rotolo et al. 2015, p. 8f).

Rotolo et al. (2015, p. 8) conclude that this example teaches us that radical novelty may characterise innovations based on both revolutionary and evolutionary inventions resulting from the speciation process.

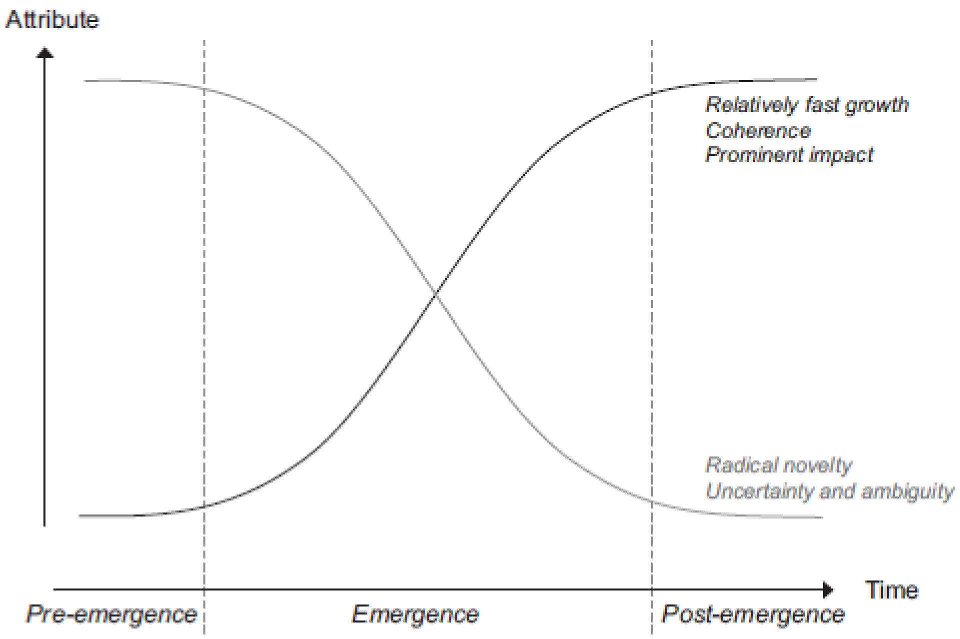
In the context of the FET programme, however, evolutionary inventions as illustrated with the example of wireless communication technology (as well as incremental innovations improving existing solutions on a small scale), are clearly not addressed. Yet, the idea of taking over concepts and approaches from one area to another is in fact something, the FET-programme supports. But this transfer is encouraged and supported in the context of technology development itself and not of its applications. Transfering concepts from one domain to another is therefore being discussed in the context of cross-disciplinarity.

The notion of ´radical´ versus ´incremental´ needs some qualification beyond the discussion of findings of Rotolo et al. (2015). In fact, the simple opposition gives the impression of a simple duality where 'radical' refers to a dramatic change influencing the economy for decades. In this perspective a 'radical' innovation is linked to long waves in the Kondratjev style. Such fundamental innovations are for example biotechnology or microelectronics. However, in most cases, a continuum between 'very radical' and 'very incremental' can be observed. In this context, Durand (1992) shows by various examples that 'radical' innovation can initiate a longer period of market success, but during this period the product or process is not only improved by incremental innovations, but various more substantial innovations can be observed which he labels 'micro-radical' innovations. In a similar way, Coccia (2003) argues that different intensities of innovation exist as a continuum instead of simply 'weak' and 'strong'. This means for emerging technologies that only a few will have a very strong economic impact. It can be assumed that their values will display a power law distribution with few extremely high values and the majority on a modest level (Clausset et al. 2009). However, compared to standard distributions, the probability of high values will be higher in the case of emerging technologies.

Another aspect where the definition of emerging technologies differs from the definition of FET programme concerns the "science-basedness" of innovations. Whereas Rotolo et al. (2015) refer to innovation in technology in general and explicitly state that "science-basedness" is not a necessary feature of their definition (ibid.: 1832), the FET programme looks for radically new concepts explicitly based in science.

The second attribute 'relatively fast growth' (of publications, patents, number of actors etc.) describes the stage of development where the new topic has already reached a quite stable status. This impression of fast growth may be due to the fact that many studies on emerging technologies are based on scientometrics which generally need 'successful' cases and refer to ex-post reflections. However, only one of the twelve 'core studies' sees fast growth as prominent feature of emerging technologies. Rotolo et al. (2015) themselves clarify the situation in emerging technologies in an illustrative graph (figure 4).

Figure 4: Per-emergence, emergence, and post-emergence: attributes and 'stylised' trends.



Source: Ratolo et al. (2015: 1833)

According to this graph, 'fast growth' only applies to later stages of emerging technologies, whereas the FET programme is focussing on a stage which is labelled 'pre-emergence' by Rotolo et al. (2015). In this stage, growth, coherence and impact are still low and novelty, uncertainty and ambiguity are high.

Other authors have analysed this transition process in more detail. For example Callon (1997) pictured the situation in different stages of emergence as transition from 'emergent' to 'stable configurations'. He described the major elements of these configurations by the features shown in Table 4. The emergent stage is characterised by a still precarious stage of knowledge which may primarily be seen as implicit. The potential application of knowledge is uncertain and the networks are instable. There is the steady risk that the network fails. In the perspective of Callon (1997), the parallel and intertwined development of knowledge and social networks is in the focus. The language describing the new topic is still unstable, the network is constantly reconfiguring, a feature that is labeled as ´uncertainty´ or ´ambiguity´ in Rotolo et al. (2015).

Table 4: Characteristics of emergent und consolidated networks according to Callon (1997)

	Emergent configurations	**Stable configurations**
Knowledge	Statements & instruments & embodied skills	Statements are information because embodied competences are duplicated
	Non-substitutability between codified and embodied knowledge	Codified knowledge and embodied knowledge are substitutable
	Private knowledge: rival and exclusive	Knowledge is public – i. e. non-rival, non-exclusive, within the network where it circulates
	Knowledge replication = laboratory replication	Replication of knowledge = coding and replication of strings and symbols
	Local knowledge is generalized through successive and costly translations	The degree of universality of knowledge is measured by the length of the network
States of the world	Lists of identity of social and natural entities constantly reconfiguring	Lists and identity of social and natural entities are known
	States of the world revealed, ex post, through trials and interactions	All states of the world are known ex ante and the probability of their occurrence can be calculated
	Uncertain and vague knowledge uses	Uses of knowledge are predictable

Modalities of action	Programs only exist ex post, as the outcome of action and learning	Research programs (problems + operation) are defined ex ante and provide a framework for action (coordination)
	Cooperation is an obligatory passage point for action i. e. for translating identities and interests and for negotiating the content of knowledge	Cooperation is a strategy for cost and risk sharing or for consolidation of power positions

Source: Callon (1997)

As the knowledge is largely implicit, the knowledge transfer between actors from industrial and from academic laboratories requires direct cooperation and communication, secrecy proves to be less relevant in this early stage. In a stable configuration, the implications of a new idea in this context can be easily replicated and instruments such as patent protection become more relevant. In the context of the FET programme, enterprise participation does not principally indicate a stable configuration, there may also be certain configurations in which enterprise participation takes place in very early stages of the development of a new concept.

In this perspective, the ambition of the FET programme is to bring completely new topics from the stage of pre-emergence to an advanced stage of emergence where the number of actors is relevant and stable and the coherence between the actors and within the knowledge is substantial and thus to support the establishment of an innovation eco-system.

Concerning the identification of emerging technologies in their early stages where the direction of the development is still uncertain, there exists a serious methodological issue, as Rotolo et al. (2015) as well as other science technology researchers have found. Rotolo et al. (2015) state that most empiric studies on emerging technologies are based on patent and publication statistics and thus need a minimal time period for trend analysis: “Measuring growth is particularly problematic for more contemporary analyses” (ibid: 1839). They see some approaches to perform analyses on contemporary data by news articles or big data sources such as Google Trends (Small et al. 2014 or Rafols et al. 2010), but these new approaches have not yet resulted in convincing new results in the context of emerging technologies (ibid.: 1339).

Another attempt is to find information in bibliographic data that might be the basis for indicators that could help in identifying and characterizing early stage emerging technologies. In their study, Winnink and Tijssen (2015) used research and development activities around the topic of graphene as a case study to find such information. However, as the authors acknowledge themselves, their approach being based on only one case study, still has to be put to the test for general applicability. And even if successful they still see the principal problem that discoveries considered at first a breakthrough might at a later stage turn out not to be a breakthrough at all.

Another finding which hints to a cautious use of bibliometric data comes from Glänzel and Garfield (2004) who analyzed the “sleepting beauties in science”-phenomenon in detail. As mentioned above, the sleeping-beauties-phenomenon states that new research topics are often acknowledged quite late or overlooked at all, mainly because they deal with approaches outside the mainstream and because of their interdisciplinary character. This finding was generally confirmed by Glänzel and Garfield (2004) as they discovered that most papers are cited within the first five years and that cases of delayed citation are rare. However, the probability is high that the papers with delayed citation have an especially high value. This value may be quantified using citation rates. But it has to be noted that principally only those cases can be detected that are cited in the first place. Other relevant ones which are not cited at all and thus forgotten do not appear in the citation analysis. Here, the reputation of the author and that of the journal may support a broader diffusion, but other signals are needed as well (Dalen and Henkens 2005) in order to decide whether or not the new concept has in fact moved from the stage of pre-emergence to that of emergence. To conclude, radically new, unconventional concepts often need special support to leave the early stage of pre-emergence and bibliometric methods can only detect certain features of the development.

A further interesting aspect of emergence is the relationship between science and technology. As to this topic, Bonaccorsi (2008) examines the dynamics of science in the last century and detects as special trigger of the growth of science being its close link to the technological progress. In this context, he uses the description “changing boundary between natural and artificial”. This intertwining of science and technology implies that new technology is increasingly not an arbitrary spinoff of science, but a direct output. In the perspective of academics, it is important that a topic is sufficiently complex for scientific research, and in the case of complex technology, the output has a dualistic character as either interesting scientific result, presented in a paper, or relevant technology, applied for a patent. For instance in areas such as biotechnology or microelectronics, the share of patents with academic inventors proves to be quite high (Schmoch 2004). To sum up, the probability that unconventional approaches in science imply the emergence of new technology has increased in the last years.

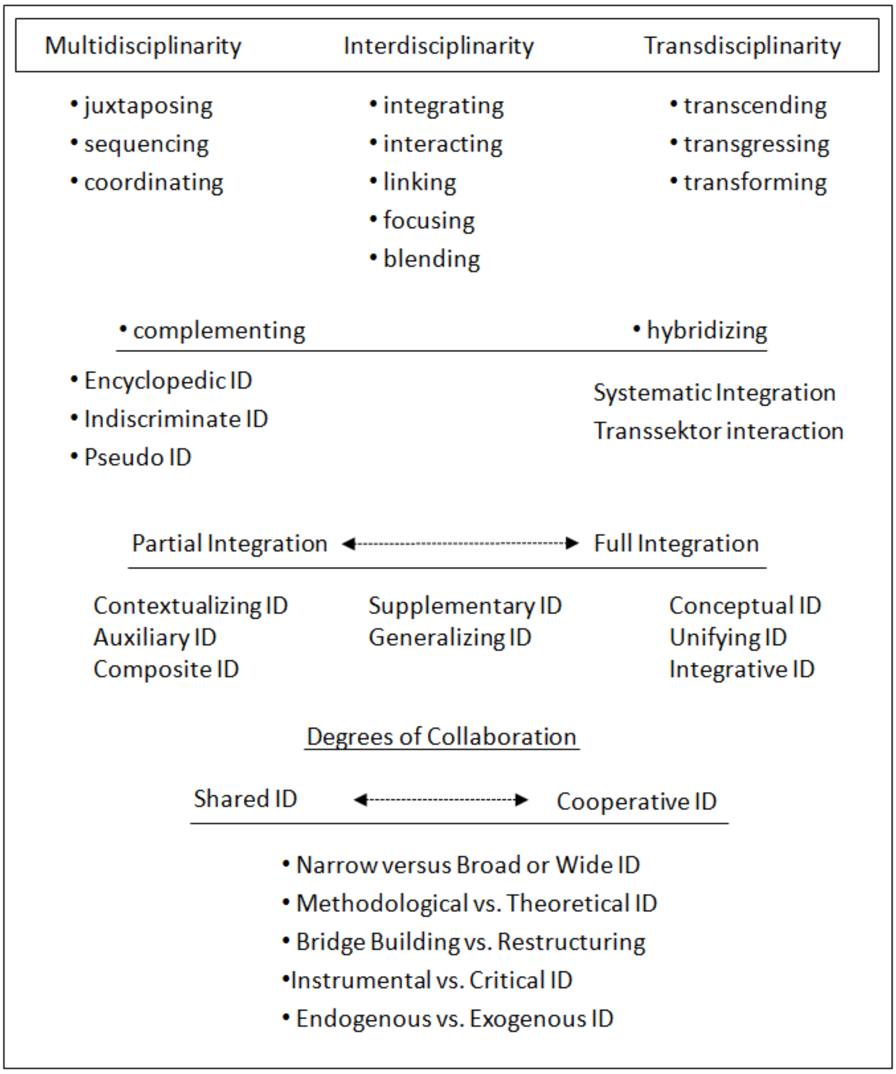
Summing up the research on emerging technologies it has to be said that most studies refer to relatively mature stages of emergence where the high impact on technology and society is already visible. In contrast, little research focuses on the early stages where the level of uncertainty is still high and a substantial coherence of the referring networks has not been reached yet. Various studies have shown that informal networks between academic and industrial researchers are important for the stabilisation of a new field, e.g. the seminal paper of Rappa and Debackere (1992) which shows the various mechanisms of the diffusion of knowledge in such ‘technological communities’. However, the mechanisms of initiating contacts between academic and industrial researchers are less known. The substantial number of projects supported in the FET programme is a good basis to collect relevant information about promising approaches to link industrial researchers to networks on emerging fields.

4 Characterizing cross-disciplinary research

Cross-disciplinarity is another important feature of research in Future and Emerging Technologies which needs some conceptual clarification. Thus, in this section, we will discuss different possibilities to define research that cuts across disciplinary borders, continue with current developments observed in interdisciplinary research, and finally show what approaches have been followed to measure interdisciplinarity.

In scholarly work, the definition of interdisciplinarity sometimes produces a "confusing array of jargon", as Julie Thomson Klein admits in her seminal article in the Oxford Handbook of Interdisciplinarity (Klein 2010, p. 15).

Table 5: Defining characteristics in typologies of interdisciplinarity (ID)



Source: Klein 2010, p. 16

Her taxonomy of interdisciplinarity includes discussions of methodological interdisciplinarity and theoretical interdisciplinarity, of bridge building and restructuring and of instrumental vs. critical interdisciplinarity (see table 5). However, the most widely used typology in research on interdisciplinarity are “multidisciplinarity”, “interdisciplinarity” and “transdisciplinarity”. These three terms form an ascending order of integration or synthesis: Whereas “multidisciplinarity” merely juxtaposes disciplinarity perspectives, “interdisciplinarity” tries to integrate different disciplinary approaches, and “transdisciplinarity” aims at an overarching synthesis of different research approaches.

Bruce et al. (2004) provide a simple description of these three approaches or stages:

“**Multidisciplinary research** approaches an issue from the perspectives of a range of disciplines, but each discipline works in a self-contained manner with little cross-fertilisation among disciplines, or synergy in the outcomes.

Interdisciplinary research similarly approaches an issue from a range of disciplinary perspectives but in this case the contributions of the various disciplines are integrated to provide a holistic or systemic outcome.

Transdisciplinary research focuses on the organisation of knowledge around complex heterogeneous domains, rather than the disciplines and subjects into which knowledge seems inevitably to become organised in academic settings, ‘transcending’ the academic disciplinary structure. (…) Transdisciplinary research (…) attempts to devise approaches which are tailored specifically to the problem context and do not rely on any predetermined disciplinary bias. (…) Transdisciplinary approaches specifically set themselves apart from discipline-based academic structures. Such approaches may also seek to break down the distinction within research programmes between researchers and stakeholders from industry or civil society” (Bruce et al 2004, p. 459).

In a similar fashion, Wagner et al. (2011) define the three main approaches as follows:

Table 6: Definitions for cross-disciplinary research according to Wagner et al. 2011

Multidisciplinary	approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment, an ad hoc mix, or a mélange. Disciplinary elements retain their original identity. In short, the multidisciplinary research product is no more and no less than the simple sum of its parts.

Interdisciplinary	approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question, or problem. The critical indicators of interdisciplinarity in research include evidence that the integrative synthesis is different from, and greater than, the sum of its parts: • Micro-combinations of models or global schemes that unify disparate approaches • Consulting and partnering modes, not multidisciplinary contracting of services • Coordinated and collaborative inputs and organizational framework • Formation of a new community of knowers with a hybrid interlanguage • Generation of new insights and disciplinary relationships • A larger, more holistic understanding of the core problem or question • Altered perspectives and revised hypotheses.
Transdisciplinary	approaches are comprehensive frameworks that transcend the narrow scope of disciplinary worldviews through an overarching synthesis, such as general systems, policy sciences, feminism, sustainability. (…) More recently, the term has also connoted a new mode of knowledge production that draws on expertise from a wider range of organizations, and collaborative partnerships for sustainability that integrate research from different disciplines with the knowledge of stakeholders in society. Here too, the transdisciplinary product is greater than the sum of its parts, though the scope of the overall effort is more comprehensive and the parts may be more diverse.

Source: Wagner et al. 2011, p. 16

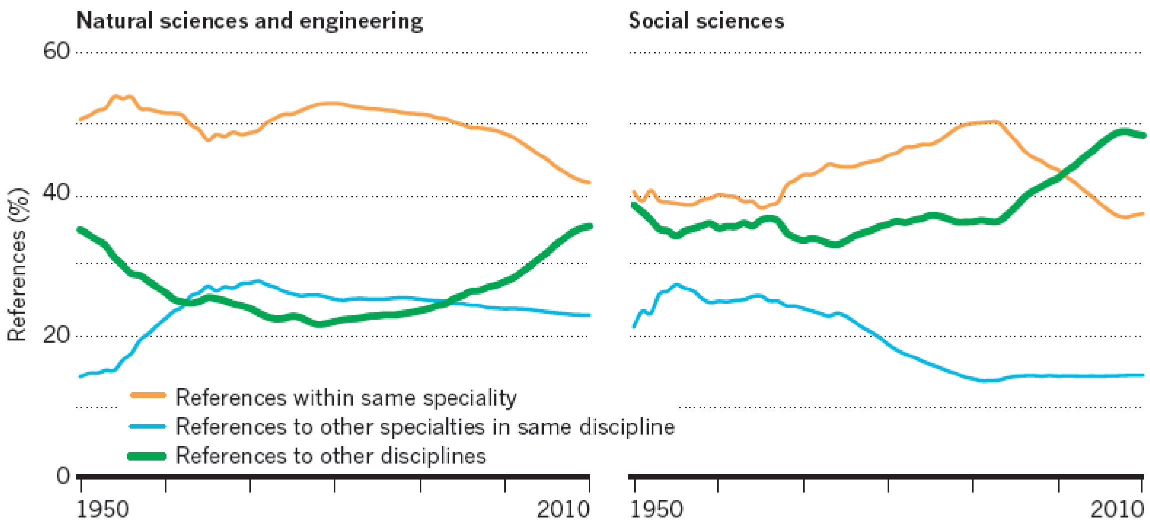
Although quite self-evident, these three-step-definitions are difficult to operationalise and the higher levels of integration or even synthesis generally require a qualitative assessment which asks for individual observations, case studies and interviews rather than quantitative assessments (Bruce et al. 2004).

A simpler way to conceptualise and quantify levels of interdisciplinarity refers to the scope of the scientific fields involved. According to Klein (2010, p. 18), “narrow” interdisciplinarity occurs between disciplines with compatible methods, paradigms, and epistemologies, such as history and literature. In contrast, “broad” or “wide” interdisciplinarity occurs between disciplines with little or no compatibility, such as the natural sciences and the social sciences. Collaboration between “distant” disciplines is generally considered more complex and difficult than collaborations between “near-neighbour” disciplines (Rylance 2015).

Current bibliometric research reveals that interdisciplinary research has been growing in the last decades, at least such interdisciplinary research that can be identified by counting scientific journal articles and citations. According to the *nature* article by van Noorden from November 2015, research papers have increasingly cited work outside their own disciplines since the mid-1980s (van Noorden 2015). He cites work from Larivière and Gingras (2014) who used journal names to assign more than 35 million papers in the Web of Science to 13 major conventional disciplines (such as biology or physics) and 143 specialities. Using the terminology from above, collaborations across the 14 major disciplines would qualify as “broad” or “wide” interdisciplinarity while collaborations staying within assigned specialities of the major disciplines would be “narrow” interdisciplinary.

As figure 5 shows, the fraction of paper references that point to work in other disciplines is increasing in both the natural sciences and the social sciences. The fraction that points to another speciality in the same discipline (for example a genetics paper pointing to zoology) shows a slight decline.

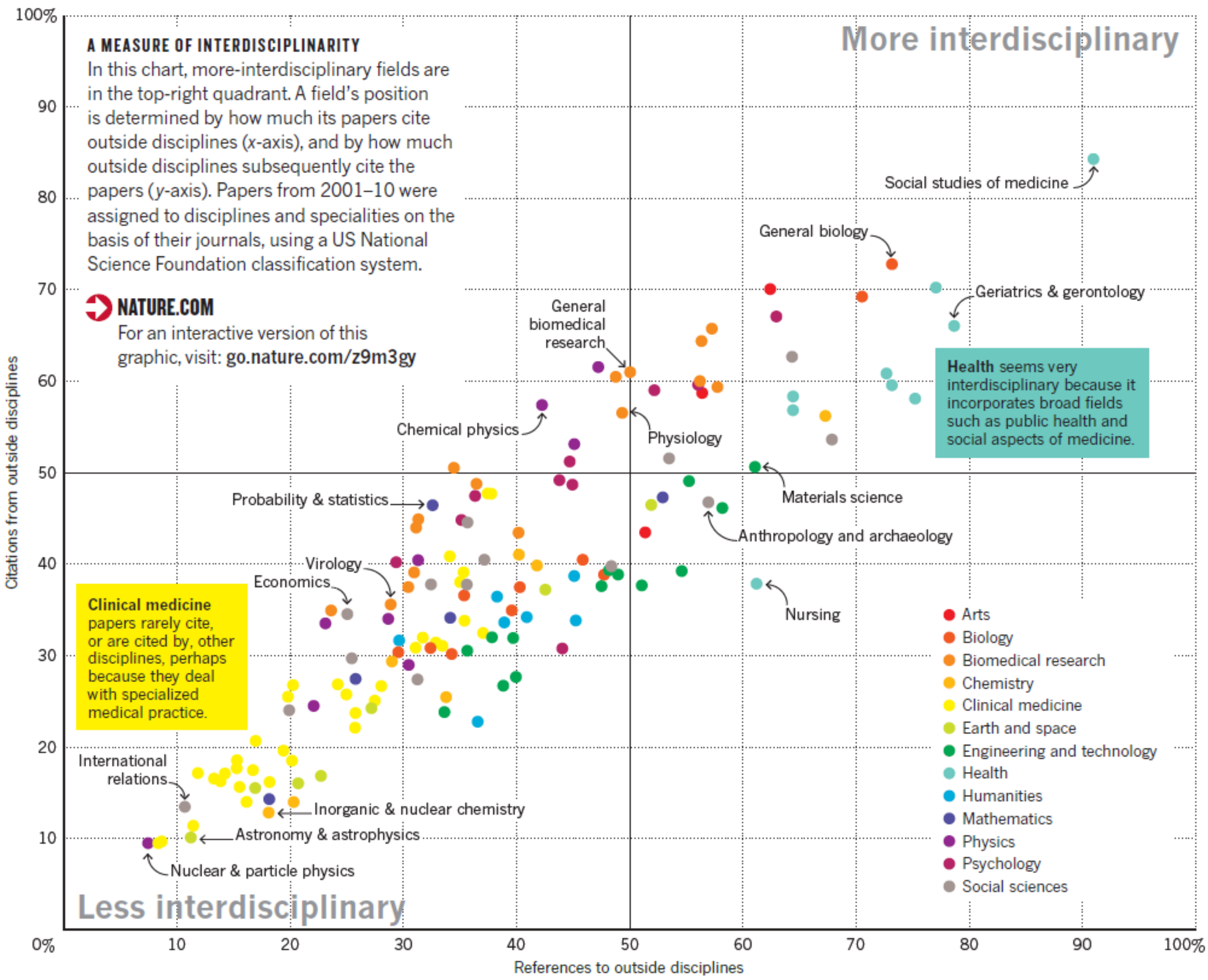
Figure 5: Interdisciplinary research is on the rise according to van Noorden 2015



Source: van Noorden 2015, p. 306

Further summarizing current research on interdisciplinarity, van Noorden states that some research fields show more interdisciplinary activities than others. In the following chart which is also taken from the *nature* article, van Noorden displays the interdisciplinary activities of the 13 disciplines (Arts, Biology, Biomedical research, Chemistry, Clinical medicine, etc.) by identifying the respective values of the 143 specialities. One example of a discipline with many interdisciplinary collaborations within its assigned specialities is “health”. The explanation given is that health incorporates diverse fields such as public health and social aspects of medicine, making the discipline interdisciplinary by design. One example given for a discipline with a low interdisciplinarity level is “Clinical medicine” for which the explanation is given that the respective specialities deal with specialized medical practices (van Noorden 2015, p. 307, see figure 6).

Figure 6: Interdisciplinarity levels of all 143 specialities according to van Noorden 2015



Source: van Noorden 2015, p. 307

Whereas there are good reasons for interdisciplinary research – first of all being the fact that complex modern problems such as climate change or resource security are not amenable to single-discipline investigation, and second being the observation that many discoveries emerge on the boundaries between fields, where the latest techniques, perspectives and insights can reorient or increase knowledge (Rylance 2015, p. 313) - scientific breakthroughs may just as well occur *within* disciplinary research. The current emphasis of governmental research programmes on interdisciplinary has also risen some doubt within the scientific community and Weingart (2000) even speaks of a “paradoxical discourse” in connection with interdisciplinarity:

“Interdisciplinarity (or transdisciplinarity and similar derivatives) is proclaimed, demanded, hailed, and written into funding programs, but at the same time specialization in science goes on unhampered, reflected in the continuous complaint about it” (Weingart 2000, p. 26).

Weingart´s thesis is that different interests can be identified in the discussion on interdisciplinarity. Whereas science policy calls for research cutting across disciplines and research fields and using terms like ”frontier research” or “research at the border” to promote innovations, research itself aims for methodological rigour, exactness, and control of errors, which many researchers think is only possible in the circumscribed area of a discipline. Weingart concludes that both, “interdisciplinarity and disciplinarity are (…) given positive evaluations for different functions: innovation on the one hand and rigour and control of error on the other” (Weingart 2000, p. 29 cited in Mutz et al. 2015, p. 31).

Whereas for example Woelert and Millar (2013) in their analysis of Australian research programmes claim that governmental research funding all too often fails to encourage real interdisciplinary because the evaluation processes of project proposals still follow a disciplinary logic, such a paradox of interdisciplinarity does probably not apply to the FET programme of the European Commission. As in the FET programme “interdisciplinarity” is considered to be the key characteristic of funded projects it might well be expected that the resulting project portfolio in fact shows interdisciplinary participations, which is the basis for successful transdisciplinary research.

FET experiences with interdisciplinary research

In a background paper of the FET Unit (European Commission 2014) titled “FET - Living interdisciplinarity”, interdisciplinarity is seen as a vehicle to “push the boundaries of information and communication technology (ICT)” by taking up approaches, models and ideas from other disciplines or specialities. Examples given for this approach are FET projects that use plant biology to develop swarm robotics or plant sensors and project that take cellular processes as a basis to improve computing technology or communication. Interestingly, in the FET-paper on interdisciplinarity, the scope of the disciplinary stretch (narrow vs. wide interdisciplinarity) is not used to distinguish different levels of interdisciplinarity. In the examples given it seems that FET projects throughout aim at a wide interdisciplinarity, combining approaches and methods from the different disciplines rather than from subfields which generally have closer links to each other.

Also, it is claimed that besides pushing the boundaries of ICT, FET projects have demonstrated radically new possibilities for other sciences and industry sectors than ICT. Examples given here are projects developing new ICT-based applications for the pharmaceutical industry or for neuroscience (European Commission 2014, p. 2).

For the FET projects to be analysed in the FET_TRACES impact assessment project, the relation to ICT is a clear thematic landmark which also structures the thinking about interdisciplinarity. It has to be noted that within the research framework programme "Horizon 2020", the thematic restriction to ICT and neighbouring fields has been abandoned. The FET programme now accepts project proposals from all of science. In future impact assessments, the definition of interdisciplinarity levels or stages has to be adapted accordingly.

In its paper on interdisciplinarity, the FET Unit implicitly follows the three-stages-definition of cross-disciplinary research as mentioned above ("multidisciplinarity", "interdisciplinarity" and "transdisciplinarity") and claims transdisciplinarity (which is called "synergistic interdisciplinarity") to be at the heart of the FET programme. But lower levels of cross-disciplinary research are also to be found in the FET project portfolio.

As the descriptions of the FET Unit summarize interesting experiences with interdisciplinarity, they shall be quoted here in more detail. Concerning the lower levels of cross-disciplinary collaborations ("multidisciplinarity" and "interdisciplinarity") the paper states that what is missing there are pathways between the disciplines "to really learn from one another. "In such cases", the paper continues, "the collaboration falls apart in disjoint discourses without a genuine synergy between them. There are many examples where promising combinations of disciplines failed in practice to even develop a common vocabulary or to show a real impact of one discipline on the other. Where this happens regularly is collaborations between ICT and experimental neuroscience or biology. Simply overcoming the hurdles of common understanding is already difficult.

On top of that, it is rarely taken into account up front how different the rate of progress will be in each 'track', and thus the opportunities for crossing over are rare and happen often late, or too late in a project. In these constructions interdisciplinarity is halted at the level of one-way 'inspiration': pick and choose what inspires, and shape it within your own discipline” (European Commission 2014, p. 2).

A special issue are one-way collaborations, in which only one partner learns from the other and not vice versa. According to the FET-paper, this can especially been observed in collaborations between the social sciences and the natural sciences: “Too often these disciplines [the social sciences and humanities] are called in when most of the technology work is done. The learning in these configurations is then also typically one-way: the social scientists will have to learn about the technology they are called for, but the technologists don’t learn about the social science (worse, they often think it is rather accessory or self-evident, hence the *pro forma*). Many technologists still need to recognise that social sciences and humanities can be helpful throughout” (European Commission 2014, p. 2).

The top-level of interdisciplinarity which the FET programme aspires to is described in the following way:

“The kind of interdisciplinarity that we are looking for in FET is a deeper one. It is an ongoing process of learning and exchange that, at least initially, deconstructs more than it constructs, because everyone involved is forced to put into question the fundamentals of its own view of the world. This is hard work and risky business. For example, it is one thing to build a cellular automaton in software, but quite something else to build a computing device with real biological cells. Everything the computer scientist knows about programming, algorithms, data structures, and so on has to be questioned. And the biologist has to try to make sense of cell interactions in terms of information exchange, rather than chemistry. This you can not do by reading each other´s books: interdisciplinarity has to be lived. But if it works, the computer scientist will think differently about computing, and the biologist about cells. The advance is synergistic.

These are probably some of the most valuable side-effects of the deep synergistic interdisciplinarity that we are looking for in FET: it breeds a kind of researcher that can bridge into the terminologies and methodologies of other fields. The permeability of disciplinary boundaries changes the way in which a researcher involved looks at its own discipline. More so, such a researcher will not be afraid to question the fundamentals of its own field from trying to genuinely understand how others look at it. This works especially well where teams don't share the same framework of assumptions that many of the harder science and engineering disciplines have (more or less) in common. Yet, this dissonance is at the heart of the kind of interdisciplinarity that FET is looking for. Certainly, this requires excellence in one´s own discipline if the obligatory 'de-construction' is not to be fatal or, at least, entirely demotivating" (European Commission 2014, p. 2).

The paper continues by stating that it is easy to call for this kind of synergistic collaboration but difficult to get it in practice. It shall be added that this also applies for measuring. However, the paper gives some hints towards possible ways of measuring successful collaborations as it lists the following components inherent to synergetic interdisciplinarity:

- Long-term stays,
- Open-ended agendas,
- Diversity in the teams (discipline, age, gender, culture, ect.),
- Measures to cultivate the right mindset (including the right to fail) and
- Ongoing mutual learning (European Commission 2014, p. 2).

Interestingly, at the lower end of the interdisciplinarity scale, the paper introduces a new level, the "pipeline collaboration": "In the well-established configurations the collaboration is one of a transaction: one discipline does its thing and hands over to the other one (a new material is synthesised, another group characterises it, and a third group works on the theoretical model). This is especially true in science and engineering. Precise planning at the outset, clear task allocation and timing are the symptoms of this kind of 'pipeline collaboration'. These are good and productive, result driven collaborations, in which one discipline provides a clear service to the other, but they are not likely to dramatically change the face of science and technology. For this, each discipline stays too much in its comfort zone of established knowledge and familiar methodologies" (European Commission 2014, p. 2). It might be an interesting question, in howfar the participation of a company in a FET project can be used as an indicator for such a pipeline collaboration.

The differentiation of levels of interdisciplinarity and the aim of the FET-programme to support truly transdisciplinary research ("synergistic interdisciplinarity") has certain implications for the impact assessement. In order to determine the level of interactivity attempted or achieved in a FET-project, different methods will have to be used. Whereas "narrow" and "wide" interdisciplinarity can be determined by identifying and counting the disciplines and specialities involved, the assessment whether a project has achieved a synergetic level of interdisciplinarity or not requires qualitative methods like interviews or case studies. Also, there is no obvious indicator for measuring "pipeline collaboration". Again, the lowest level of interdisciplinarity requires qualitative methods to identify.

The question of how to measure interdisciplinarity scientific research is discussed on a conceptual level for example by Wagner et al. 2011 in their literature review of the different methods commonly used. They state that the different available definitions, assessment tools, evaluation processes and measures "all shed light on different aspects of interdisciplinary research" (Wagner et al. 2011, p. 14) and emphasize the importance of incorporating the concept of knowledge integration. Integration is considered a cognitive or social process, "whether it takes place within an individual's mind or within a group, so that a valid assessment of the interdisciplinarity of research must involve some indication of the degree or extent of knowledge integration that took place *as the research was being conducted*. (Wagner et al. 2011, p. 16 emphasis in original). The authors further specify that integration also entails negotiation of conflict and achievement of synthesis. They cite Rafols and Meyer (2010) who use a concept of integration that reflects two aspects of knowledge systems: (a) diversity, or the number, balance, and degree of difference between the bodies of knowledge concerned; and (b) coherence, or the extent to which specific topics, concepts, tools, and data used in a research process are related. (Wagner et al. 2011, p. 16). It is obvious that these kinds of information cannot be extracted from quantitative methods but require carefully prepared qualitative methods.

On the other hand there is a set of quantitative methods for measuring interdisciplinary research which is well established and which can shed light on certain output dimensions of interdisciplinary research. Among the quantitative measures, bibliometrics (co-authorships, co-inventors, collaborations, references, citations and co-citations) are the most developed, and Wagner et al. 2011 discuss the uses and advantages of these methods but state that quantitative measures alone cannot adequately capture the whole phenomenon. They recommend combinations of quantitative measures and qualitative assessments in evaluation studies admitting that this carries burdens of expense, intrusion, and lack of reproducibility year-upon-year.

One of the important hints from Wagner et al. (2011) is that interdisciplinarity can be measured either as an input, as a process or as an output value – or as a combination thereof. Output can be measured by bibliometric methods, but process as well as input values obviously cannot. A possibility to describe and evaluate processes of integration are case studies based on interviews with the involved researchers. A way to describe input values of interdisciplinarity is to find out which disciplines or scientific subfields are involved in a certain collaborative research project and describe the disciplinary stretch of the involved researchers.

Current research also indicates that cross-disciplinary collaborations and projects at the intersections of traditional disciplines and research fields are the places where new insights are being gained and where potentially transformative technologies are being developed (Bogner et al. 2010; Wagner and Alexander 2013).

5 Experiences from similar projects

Additional input concerning the question of how to measure interdisciplinary research but also how to conceptualize and measure novelty, and technology-orientation comes from an analysis of similar impact assessment projects which have been carried out by the FET_TRACES project partners AIT and ISI. Table 7 lists the projects considered for this purpose and the main research question.

Table 7: Projects of the project partners with relevant insights for FET_TRACES

Title	Year	Main research question
Development of a bibliometric model for the identification of frontier research **(DBF)**, project of AIT for the ERC	2013	Develop a bibliometric model which allows for the assessment whether or not ERC has funded new, risky, interdisciplinary, and application-oriented research projects.
Emerging Research Areas and their coverage by ERC-supported Projects **(ERACEP)**, project of ISI for the ERC	2013	Identify emerging research areas and to analyse to what extent ERC projects actually over these new research areas.
Identification and assessment of promising emerging technological fields **(PROM-TECH)**, project of AIT and ISI for the European Commission	2007	Identify promising new and emerging technologies which are science-based and in their early stages by using advanced bibliometric methods.

In the **DBF-project**, the Austrian Institute of Technology developed a scientometric-statistical model to identify “frontier research” in projects funded by the European Research Council (ERC). For the investigation, ERC project data (applications as well as granted projects) could be used which was then contrasted to bibliometric data (publications and keywords) from the publication database PASCAL. “Frontier research” was defined as research that reaches beyond horizons of existing knowledge by being intrinsically risky endeavours without regard for established disciplinary boundaries. Based on this definition, four key attributes of frontier research were developed:

- Novelty of the proposed research
- Risk of the investigator through establishing scientific independence and/or taking on a new research field
- Applicability (entrepreneurial principal investigator or proposed research)

- Science of interdisciplinary nature

These four attributes were then translated into five indicators that could be expressed in bibliometric terms:

- Timeliness
- Risk
- Innovativeness
- Interdisciplinarity
- Pasteuresqueness

The indicators timeliness and risk were derived from citation analysis, whereas the indicators innovativeness and interdisciplinarity were derived from lexical analysis. The indicator Pasteuresqueness was based on patent counts and journal classification (ratio of applied vs. theoretical) of applicant publications.

The indicator **Timeliness** was based on the assumption that the time (publication year) distribution of cited proposal references is a proxy for the novelty of research. The more recent the references were, the more likely the work was considered to be at the cutting edge of science. Timeliness computes for every reference of a proposal the relative difference in years between its publication date and the year the proposal was turned in at the ERC.

The indicator **Risk** was used as a proxy for the “individual risk” of the principal investigator in carrying out the proposed research. Again, we made use of references given in the proposal. We identified references of research papers previously published by the applicant and compared these with the other references given. The overlap between both sets was used to compare the proposed research direction with respect to past research. The underlying assumption was that the lower the overlap between the sets, the more it is indicative of a change from previous pursued research. Computationally, the indicator is defined by the correlation coefficient.

The indicator **Innovativeness** was based on a lexical analysis which is a bibliographic matching technique based on keywords which requires to determine independent science trends first. We used the indicator innovativeness as a proxy to infer the “novelty” of a proposal. The core concept had two main steps. 1) The construction of a “publication landscape” via a cluster map derived from scientific and technological information (including research publications, excluding proposals). The landscape was created for two time steps to characterise its level of change over time and identify resp. rank clusters with dynamic growth. 2) Each proposal was ‘embedded’ into the landscape to compute an innovativeness value depending on both distance and rank of nearest clusters. The underlying assumption was that the closer a proposal is to clusters of dynamic growth, the more novel it is.

Computationally, innovativeness was based on indexing keywords. To this end, the bibliographic database PASCAL was used which provides a broad multidisciplinary coverage of about 20 million records. Each PASCAL record was indexed, either manually by scientific experts or automatically based on content analysis, with both keywords and thematic categories. Raw data were extracted from PASCAL (for international scientific and technological literature) by employing a query derived from the description of ERC main research fields (15 in 2007, since then expanded to 10 fields in Physical and Engineering Sciences and 9 fields in Life sciences).

Subsequently diachronic cluster analysis was used to study the evolution of the publication landscape across time windows. The most recent time window was the year in which proposals were submitted. Structural alterations of clusters between two time windows were identified and analysed by human scientific experts. Techniques of association rule extraction were applied to facilitate the cluster analysis, using fuzzy association rules. There were two objectives: 1) Determining which clusters carry novel topics and to rank clusters by their ‘novelty index’ (a measure of the relationships between clusters from the two time windows build on association rules). 2) Evaluating the novelty of proposals by their similarity with respect to clusters with a high rank.

The indicator **Interdisciplinarity** was used as a proxy to infer self-consistently the presence and proportions of characteristic terminology associated with individual ERC main research fields, thereby revealing the intra- or inter-field character of a proposal. It was built upon the previously successfully tested approach (Schiebel et al. 2010) that the frequency of occurrence and distribution of research field specific keywords of scientific documents can classify and characterise research fields. While the core of the approach has been retained, the computation has been adopted and fine-tuned to the grant scheme under study.

The indicator **Pasteuresqueness** served as a proxy for the applicability of expected results of each proposal. It was based on patent counts and journal classification (ratio of applied vs. theoretical) of applicant publications. Input data was obtained from proposals and external information sources (e.g. bibliographic databases).

Main conclusions of the DBF-project include that the chosen indicator for risk did not adequately match the notion of risk of the ERC, obviously, DBF understood “risk” in a different way than the ERC. Also, discussions around the definition of the interdisciplinarity indicator showed that using keywords is only one of many ways to define interdisciplinarity. Another discussion was that of the interaction between the different key attributes. During the project, the individual proposals were ranked according to to all five indicators. However, it was never clear whether a really successful proposal should score highly on all five accounts. Another experience from the DBF-project was that the translation of the key attributes into the indicators risk and pasteuresqueness was especially difficult. This was due partly to the need to pin down the concept to a single issue that could be measured in bibliometric terms.

On the basis of these five indicators, it could be suggested that using indicators that look at the content of the proposal (interdisciplinarity and innovativeness) rather than only the citations or references in isolation (risk and timeliness) proves to be more successful. The project found that not only was it easier to define these two indicators (interdisciplinarity and innovativeness) but that they also played a statistically significant role in the peer review process. The output of the project was a ranking of proposals calculated for each of the individual indicators. This information in itself was considered a success of the DBF project. Although the indicators developed may not represent a complete reflection of the ERC´s understanding of frontier research, they pick up some of the aspects of frontier research, and can therefore serve as useful inputs in an evaluation context of grant proposals or peer-review processes for different purposes. (AIT; INIST-CNRS 2013).

The **ERACEP-project** also dealt with research funded by the European Research Council (ERA). However, whereas in the DBF-project, several dimensions for ERC-proposals were analysed (timeliness, risk, innovativeness, interdisciplinarity, pasteuresqueness) and the aim was to develop an innovative bibliometric model to assess the review process of the ERC, the ERACEP-project focused on only one aspect of ERC projects: their coverage of emerging research topics. In order to analyse to what extent ERC-projects cover new research areas, a combination of two perspectives was necessary: The first perspective concerned the identification of emerging research areas. The second perspective took the view of ERC funding and explored how ERC-funded research themes map to the identified emerging areas.

For that matter, the ERACEP-project adopted a bibliometric approach which consisted of two building blocks. The first building block comprised the identification of dynamic research fields based on publication activities. The rationale behind this approach was the notion that dynamic growth of a specific field reflects an increasing interest of scientists in this field, so that more research groups are doing research in the respective area resulting in a growing number of scientific publications. The second building block designed for the detection of emerging topics within dynamic fields consisted of three bibliometric components: a cluster analysis of the fields, a fine-grained representation of clusters based on core documents, and a diachronic analysis of the evolution of links among clusters and topics over time. For the identification of the dynamic fields a Sharpe Ratio was calculated for all the subject categories included in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts and Humanities Citation Index of Thomson Reuters. The Sharpe Ratio considers the development of a specific field in relation to the growth of all fields. Thereby, it allows for adjusting to differences in absolute field sizes. As a result of this dynamic analysis, thirteen fields were identified from the natural sciences, four from the social sciences, and three from the arts and humanities. Overall, the dynamic analysis using the Sharpe Ratio proved to be a powerful indicator of growth and an appropriate criterion for the selection of the most dynamic fields, resulting in a portfolio of quite diverse dynamic fields covering all categories of science.

For the detection of emerging topics within the retained sample of dynamic fields, two methods were used: bibliometric coupling and keyword analysis. Bibliographic coupling has the clear advantage compared to co-citation analyses that basically all papers have references which can be used for coupling and that no response time is needed as for citing literature which is crucial for a citation-based approach. The keyword analysis was based on term frequency analysis, where terms are analysed which were extracted from titles, abstracts, and keywords of publications. Both methods were combined to a hybrid measure of similarity between documents which formed the basis for clustering. For labeling and representation of clusters with core documents was used. These were defined as documents which are strongly linked with many other documents, and thus represented the most interconnected part of the network. As a result, ten emerging topics could be identified.

The overall experience with the approach chosen in the ERACEP-project was that the bibliometric cluster analysis has proven to be a powerful methodology for identifying emerging fields of science. However, it also became clear that there is a need to complement the quantitative statistical analysis by qualitative expert assessment in order to obtain robust and validated results.

For the second part of the project, the mapping of the detected emerging topics to the ERC-proposals, a data sample of 932 applications to the 2009 Starting Grant Call of the ERC could be used. A full-text-matching approach was chosen. As a first step, a database of publications and a database of applications were set up in parallel. Then, the text fields in the databases were indexed using the LUCENE text index. From both indexes, a set of common terms was extracted. Document-by-term matrices were created containing the raw frequency of each term in the document. After applying a weight to term frequencies, the matrices were combined into a paper-by-application similarity matrix. Taking the average similarity over papers within a certain topic resulted in the final topic-to-application similarity matrix. For the validation of the results of the mapping a manual qualitative procedure was used. As a result of the matching exercise it could be said that ERC funding indeed is able to address emerging topics, however, we observed substantial differences across the different topics: Some were reflected in a quite large number of ERC projects and in some emerging topics, ERC projects were very rare or did not exist at all (Fraunhofer ISI; ECOOM 2013).

The **PROM-TECH-project** aimed at identifying promising emerging technology fields. Its approach was based on the observation that many new emerging technologies of the last decades were technical applications of new research results stemming from physics or from the intersections of physics, biology and the medical sciences. An example of the relevance of physics for emerging technologies is coating with specific characteristics which can be achieved by Physical Vapor Desposition (PVD). Also, research on ceramics closely related to physics aims at using this material as specific sensors. One example of applications originated at the intersection of physics and biology is the use of biological material as a new medium for storage of digital data.

In order to observe new trends in their early stage, the PROM-TECH-project started with a bibliometric analysis of scientific publications. We looked for bibliographic references dealing simultaneously with either technology areas or physics, biology or the life sciences. The searches were done in the database PASCAL which provides broad multidisciplinary publications covering about 15 million bibliographic records. PASCAL includes international publications in mathematics, physics, chemistry, earth sciences, applied sciences (engineering) and life sciences. Furthermore, the database employs a sound and deeply differentiating classification system and allows publications with multiple disciplinary classifications. The queries we used were exclusively based on the classification categories given in the PASCAL-database. The first analysis resulted in roughly 200 technology fields. As we were interested in the development over time of the obtained applicative fields, we produced data for four time series covering the years between 1996 and 2003. By this method we were able to reduce the number of relevant new technology fields to 40. In a final step we asked experts to assess these 40 fields and prioritize them according to their expected impact.

The main result of PROM-TECH was the identification and short description of 10 emerging technologies with highly strategic relevance for the near future. Furthermore, we have identified the scientific community in detected emerging technologies which might become key players in these fields (PROMTECH 2007).

6 Characterizing innovation eco-systems

The notion of an innovation eco-system conceptually builds on insights from biological ecosystems observed in nature. According to Jackson (2011), the biological ecosystem is a “system that includes all living organisms (biotic factors) in an area as well as its physical environments (abiotic factors) functioning together as a unit. It is characterized by one or more equilibrium states, where a relatively stable set of conditions exist to maintain a population at desirable levels. The ecosystem has certain functional characteristics that specifically regulate change or maintain the stability of a desired equilibrium state. In the biological system, the equilibrium state is described by modeling the energy dynamics of the ecosystem operations. (…)

In contrast, an innovation ecosystem models the economic rather than the energy dynamics of the complex relationships that are formed between actors or entities whose functional goal is to enable technology development and innovation. In this context, the actors would include the material resources (funds, equipment, facilities, etc.) and the human capital (students, faculty, staff, industry researchers, industry representatives, etc.) that make up the institutional entities participating in the ecosystem (e.g. the universities, colleges of engineering, business schools, business firms, venture capitalists, industry-university research institutes, federal or industrial supported Centers of Excellence, and state and/or local economic development and business assistance organizations, funding agencies, policy makers, etc.)” (Jackson 2011, p. 1f)

In fact, the concept of innovation ecosystems suggests to look at the whole system and not at separated sub-areas and consider the different relations between the actors participating in the eco-system. The analogy ends however, when outputs are considered: Whereas biological ecosystems strive at certain equilibriums, innovation eco-systems´ rationale is growth.

After describing the different roles of academia and especially of fundamental research on the one hand and the enterprise sector on the other, Jackson (2011) concludes: “In summary, fundamental research is a necessary ingredient for the development of transformational innovations that have potential for impacting economic growth. Given that the investment in fundamental research comes at the expense of profits, a healthy innovation ecosystem is one that closes the feedback loop between R&D investments through innovations that increase profits in the commercial economy”. (Jackson 2011, p. 12).

The concept of innovation ecosystems is closely linked to the innovation systems approach (Lundvall 1992), which hints to the importance to look at the innovation process in a holistic manner. The advantage of the concept of national innovation eco-systems is that policy strategies that drive innovations can be better identified compared to the more analytical innovation system approach (Yawson 2009, Durst and Poutanen 2013).

A main line of thought within the innovation ecosystem approach is that results from basic research need to be transferred to technologies and finally marketable products in order to be valuable for the whole system. Research funding has faced this challenge using different approaches, one being the introduction of the Technology Readiness Level-concept (TRL) which classifies the innovation process from the early stages to the commercial exploitation. For example, in the Nanotechnology, new Materials and production technologies (NMP) thematic area of FP7 of the European Commission, research projects had to assess their TRL at the beginning of the project and describe the activities planned to achieve a higher TRL during the course of the project. At the end of the project, the success of the project was assessed according to the TRL which could finally be reached (Enzing et al. 2015).

In the context of the FET programme of the European Commission it has to be noted that the aim of developing marketable products from science is not the only goal. In fact, creating innovation eco-systems is only one aim of the programme. At the same time, the programme intends to support long-term, high-risk, and potentially high-reward research. This means that the FET programme asks for the development of marketable applications and at the same time encourages truly novel research at the cutting edge of science. At first sight this looks like a conflict of interests. In fact, when analyzing the project portfolio of FET, we expect to see application oriented projects with enterprise participation as well as projects where researchers are hoping for new insights at a mere conceptual level.

From a conceptual point of view this does not have to be throughout contradictive. Instead, as the notion of “Mode 2” science (Gibbons et al. 1994) suggests, mutual stimulations between basic science and application oriented science and even research carried out in company R&D are the mode in which science as well as applications flourish. Instead of a linear model of innovation, this concept suggests a circular model of innovation in which contacts between academia and company R&D are responsible for innovations, especially in future and emerging technologies.

In the chapter characterizing FET like research we have already reflected on the necessity of cooperation between academia and the enterprise sphere, emphasizing the need of scientists to communicate their research results not only to the academic field but also to the commercial area. Principally, there are many ways in which scientific results may be used to develop new technologies and products – and equally there are many ways how new technologies may inspire new research.

A list of possible activities to exploit the innovation potential of FET research was compiled at an expert workshop held in February 2015 at DG Connect (DG Connect 2015). The aim of the workshop was "to identify the main ingredients of an innovation eco-system capable of realising the latent innovation potential of FET research and to suggest support actions that could foster such an eco-system" (DG Connect 2015, p. i). The experts of the workshop suggested seven future activities and clusterd them into two groups. The first group suggests activities which aim to amplify the intrinsic innovation potential of FET research:

- The inclusion of a call for projects tackling 'Extreme Challenges' to stimulate high-risk, high reward projects based on disruptive ideas and novel approaches that could lead to radically new, innovative outputs and valuable unexpected products;
- 'Second-stage Funding' for FET projects demonstrating a high innovation potential, provided via a call for follow-up projects involving an industrial participation.
- Greater efforts to stimulate and facilitate the 'Inclusion of SMEs' in FET projects, to add an innovation-oriented element while maintaining the 'dream-driven' spirit of FET research;

The second group lists activities which are suited to stimulate the up-take of FET research results:

- A 'Proof of Concept' scheme providing funding aimed at bridging the gap between embryonic FET research results and demonstrations of 'proof of concept' that would stimulate up-take by industry and be attractive to potential investors;
- A series of 'Network Industry Events' aimed at bringing researchers and industry together;
- An 'Open Day' for investors, to expose FET results to potential investors;
- The establishment of 'Innovation Labs' or 'FET Schools of Innovation', to offer a platform for educating FET researchers about the needs of the business community and vice versa, and to provide entrants with innovation- or entrepreneurial-related qualification;
- 'Innovation-oriented Coaching and Training', delivered via a variety of routes and designed to make FET researchers more aware of their specific role. (DG Connect 2015, p. if, see also FET Advisory Board 2015).

The paper emphasizes that besides the strengthening of the innovation ecosystem activities, the FET programme shall maintain its focus on long-term, high-risk and novel research (DG Connect 2015, p. ii).

7 Characterizing the European research landscape and the specific role of the FET scheme

From a conceptual point of view, the aim of the FET programme to become an important player within the European research funding landscape has two aspects. The first aspect concerns research policy and the ability of the FET programme to create legitimacy and institutional strength vis á vis the other European research funding institutions. The second aspect relates to the researchers themselves and their perception of the FET programme to be an exciting, appropriate and prestigious funding instrument for their research ideas and personal careers. Although both aspects are connected, we will look at them separately.

One important prerequisite for the FET programme to further develop institutional strength is a convincing positioning within the European funding landscape which emphasizes its unique features and which is able to demonstrate its special contribution within the European innovation system. As mentioned in the introductory section of this paper, the FET programme is currently mainly positioned against the European Research Council (ERC), the Marie Skłodowska-Curie actions, and the Research Infrastructures programme. Summarizing the main unique features of these programmes, table 8 shows the positioning of FET alongside the answers to the two most basic questions in science research: “How are scientific insights being achieved?” and “How can scientific results be transferred to new technologies and applications?”

Table 8: Answers of different European research funding instruments to the two basic question of science and innovation research

How are scientific insights being achieved?	
ERC	By supporting young and established researchers and selecting them solely by their scientific excellence
MSCA	By encouraging international exchange through financing research stays in foreign research institutions
Infrastructures	By digitally connecting researchers and giving them access to scientific archives and big data resources
FET	By supporting collaborative, interdisciplinary projects and encouraging researchers to focus on new ideas and technological advances

How can scientific results be transferred to new technologies and applications?	
ICT/NMP and other schemes within H2020	By supporting R&D projects which combine existing technologies, build prototypes or pilot lines pushing new technologies up on the level of technology readiness (TRL).
Other instruments	By supporting start ups, supplying venture capital, build topical clusters, support exchange, etc.
FET	By supporting basic science projects which may lead to new technologies with a potentially transformative character.

The Finnish innovation researcher Terttu Luukkonen has analysed in depth strategies of building institutional legitimacy at the example of the ERC (Luukkonen 2014). She emphasizes that funding bodies or schemes aiming to ensure legitimacy must have differentiated objectives and strategies. Concerning the positioning of FET she recounts the history of its establishment and its current position as follows:

"FET has been a part of the Information and Communications Technologies (ICT) programme since FP3, whereas the New and Emerging Science and Technology (NEST) programme was only initiated in FP6. Both programmes have promoted new scientific and technological opportunities and emerging scientific and technological fields and have been built on the traditional principle of collaborative research. The FET programme has a completely open-ended/early exploratory action line and one that is proactive in specific actions. The NEST programme also had specific action lines with frames with varying degrees of openness. The NEST programme was not continued in FP7. The unit that was responsible for the NEST programme made the preparations for the ERC, and the European Commission officials viewed the NEST programme as a predecessor to the IDEAS programme (and the ERC). Its discontinuation in FP7 (despite the differences in objectives and tools) is an example of the negative coordination (…) making room for the new organisation to avoid overlapping activities. In contrast with the NEST programme, the FET programme has continued in FP7, and its resources have grown towards the end of FP7 (…). The weight of the FET programme as a 'pathfinder', a purpose-driven programme to develop future industrial ICT agendas, is increasing rather than decreasing (…). Furthermore, in the proposal for Horizon 2020 (…), the FET programme will also be opened for other fields (…). Thus, it appears that when the ERC first replaced the NEST programme, the FET programme later assumed the earlier role of the NEST programme as a new collaboration-based explorative scheme and as part of the strengthened excellence pillar of the new framework proposal. Thus, the ERC and the expanded FET programme are viewed as complementary rather than competing schemes." (Luukkonen 2014, p. 37).

The second aspect to build legitimacy concerns the researchers themselves. The FET programme aims at attracting the best researchers in Europe and has the ambition to support the most innovative projects in the area of future and emerging technologies (FET Advisory Board 2015). This requires a level of visibility and a positive image to eventually draw in the best researchers into FET projects.

Again drawing from Luukkonen´s analysis of the ERC, an assessment of the image of FET needs to consider aspects which are relevant for researchers in their attempt to draw in money for their research and to further their academic career. The following table displays results from Luukkonen´s survey of ERC grant holders taking into account seven features which make up the attractiveness of a funding programme or institution:

Table 9: Ratings of various funding organisations: ERC Starting Grant recipients

Attractive feature of respective funding organisation	High reputation/ prestige	High-quality peer review	Low administrative burden	Appropriate grant size	Enables novel/ innovative research	Enables international collaboration	Helps significant research findings to be achieved
Own university	19%	9%	25%	7%	19%	28%	12%
National funding agency	14%	27%	21%	20%	28%	23%	28%
ERC	66%	49%	26%	66%	64%	46%	56%
ESF	4%	4%	2%	1%	5%	9%	1%
EU FP (excluding ERC)	15%	6%	3%	17%	12%	33%	12%
Industry	3%	1%	9%	6%	7%	1%	6%
Charities	9%	5%	25%	10%	14%	12%	12%

Source: Thomas and Nedeva (2012) cited in Luukkonen 2014, p. 36. Percentage of survey respondents; N=138.

These and other factors will have to be considered when assessing the image of the FET programme in our own survey. Especially aspects covering issues of interdisciplinarity have to be added at our survey.

8 Consequences of the literature review for the impact assessment: Implications for indicator building

In this section, we describe the consequences of the literature analysis on relevant aspects for the impact assessment along the four impact dimensions “novelty”, “innovation eco-systems”, cross-disciplinarity” and “becoming a relevant player in the European research funding landscape”.

Novelty

It is important to see that new developments originating from FET projects are at a very early stage when looking at the double-boom-cycle. Thus, it should not be expected to see strong impacts in a short delay, especially from projects which were finished quite recently. However, one of the main goals of the FET programme is also to transform scientific insights into technologies and build an innovation-ecosystem around the new technology. Thus, there may be cases where the absolute novelty of an idea is not the ultimate criterion. FET-projects may use concepts which are not absolutely new but which have not yet been transferred into concrete applications or which have not gained widespread attraction. Radical novelty might in such cases be complemented by „pretty new but not yet well-known“.

Cross-disciplinarity

Interdisciplinary and especially transdisciplinary research as defined in the above section may be used as a proxy for novelty. An open question is whether participation of more disciplines automatically results in a higher degree of novelty or “disruptiveness”. As was described in the section above, there are many conceptual approaches as to what cross-disciplinary research might be. Yet, to make it measurable, a simple 3-level scale is suggested for the characterization of FET projects in the portfolio:

1-pipeline collaboration (low)

2 narrow interdisciplinarity (middle)

3 wide interdisciplinarity (high)

A fourth level “synergistic collaboration” might be included in a series of projects, especially those being highlighted in the FET-paper on interdisciplinarity. However, since “synergistic collaboration” is an assessment in itself, an adequate use of the term requires a qualitative assessment, which is much more than just counting the participating disciplines and research fields. It is forseen to carry out an assessment of the quality of the interdisciplinary collaboration in the context of the case studies planned in the course of the FET_TRACES project.

Whereas counting the number of different disciplines involved in a FET project describes the input side of interdisciplinarity, we will also carry out a bibliometric analysis which takes care of the output side of interdisciplinary research conducted in FET projects.

Innovation eco-systems

Whether or not a FET project was able to start an innovation eco-system can be measured using the indicators „citation rate“ as a proxy for the diffusion of the idea within academia, „number of industry contacts” as an indication for industry relevance of the idea and finally “patent application financed by an enterprise”. The following results from the above sections shall be highlighted:

- Publications in scientific journals which are cited by others indicate that the idea, approach or concept developed in the FET project is relevant to other researchers. So, a first assessment of the impact of a FET project will look at the bibliometric footprint of the respective project. If we know which publications came out of FET projects, we can tell whether other researchers are taking up the results by identifying follow-up publications. The follow-up publications might also be from other research groups.
- Another indicator coming from the conceptual discussion concerns co-publications: As soon as researchers from academia and R&D people from industry jointly publish an article in a journal, this indicates that the involved FET project partners did not merely wait for their idea to become known by publishing it in scientific journals. Rather it indicates diffusion activities of the FET project partners to make their idea known in the engineering and technology development community. Co-publications indicate that the FET-project has started something new which matters to the technology community. Finding co-publications indicates that the idea is relevant for enterprises and might become an economically relevant topic. Also, it shall be looked whether there are publications on this topic from other researchers or research groups. This is also a sign that the topic is relevant and spreading into the community.
- Also of special interest are conference contributions, especially at conferences with industry, for example IEEE-conferences because they also indicate industry-relevance of the new concept. When asking FET project partners directly, one question would be “What are your activities concerning industry contacts?” Furthermore we can see in bibliometric databases whether the FET promoted

scientists have published in proceedings of technological conferences with industrial and academic audience.

- Patent applications are a good indicator for determining the industry relevance of a new idea. Although this might be too early for many FET projects, patent applications show that something new has been started and and that the idea is not purely academic, but might also be of interest for industry.

Citation numbers, co-publications, conference contributions and patent applications are indicators for follow-up activities which are important for a new idea to spread into the scientific and technology development community. The impact analysis of the FET programme thus is to a large part an analysis of follow-up activities. Consequently our assessment will focus on how active FET project coordinators or partners have been in spreading their idea, in further developing, refining and concretely applying their idea originally developed in the context of a FET project.

Becoming a relevant player

In the above section, we have described what the aim of becoming a relevant player within the European research funding landscape implies. For the impact assessment, two aspect shall be highlighted: The empirical work in FET_TRACES should aim at finding FET research results which are suited to illustrate the unique features of FET-like research and describe where FET projects have achieved breakthrough results or have contributed to important developments. The other important aspect is to find out, how well-known or unknown the FET programme is in the scientific community and what image it has with those researchers having been in contact with the programme.

9 Literature

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