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

Document history

Version	Date	Changes
1.0	25 July 2017	
2.0	29 August 2017	Extended the methodology section and included additional analysis in the results section.
3.0	12 September 2017	AIT comments and additions included

Contents

1 Introduction

The objective of this deliverable is to trace the diffusion of ideas originally developed in FET projects into the scientific community and the industrial R&D community by using bibliometric methods.

Our bibliometric analysis will trace the diffusion of the FET supported concepts and will show the specific structure of the diffusion. Our aim is to identify FET projects with strong impacts in the scientific area as well as FET projects with a relevant industrial impact. Also, we aim to identify the interdisciplinarity level of FET projects for which we will use citation rate analysis.

As we have described in the indicator report (D3), the bibliometric method covers a specific set of indicators. These indicators are listed in table 1:

Table 1: Indicators for the bibliometric analysis

Method	**Indicators**
Bibliometrics	Relevance I: Number of scientific publications originating from a FET project
	High impact scientific publications: Number of FET publications in *nature* and *science*
	Relevance II: Publications with industrial partners (bibliometrics and survey)
	Output interdisciplinarity: Number of projects with publications in different subject areas in the Web of Science
	Community building I: Transfer of new ideas into the scientific and industrial R&D community - Number of citations of FET-project related publications.

Originally, the list of indicators for the bibliometrics method covered even more aspects, like input interdisciplinarity or publications with partners originally not involved in the FET project (see appendix 1). However, it turned out that some of the very sophisticated indicators - like the number of publications with industrial partners originally not involved in the FET project - were not possible to be checked with bibliometrics. Thus, we used the survey instead (see D7.1) where we asked FET participants directly about these aspects.

On the other hand, in the course of carrying out the bibliometric analysis, it turned out that indicators could be provided which were initially not thought of. For example, as the data was available for determining the output interdisciplinarity, we were also able to calculate the interdisciplinarity stretch of FET publications. This means that we are able to say which project results were not only relevant within its neighbouring research fields but also in more distant disciplines.

Concerning the impact dimensions which are described in more detail in the conceptual paper (D1), the bibliometrics deliverable covers the "innovation eco-system" dimension (relevance and community building), the dimension of "multi-disciplinarity" (output-interdisciplinarity) and the "novelty" dimension (publications in *nature* and *science*, suggesting excellence equals novelty).

2 Method

The following assessments refer to the bibliometric characteristics of 224 projects conducted within the FET programme.[1] In order to carry out the bibliometric analysis, three steps of data gathering were necessary:

1. To identify all publications which can be assigned to the 224 FET projects in our sample which includes an assignment of sets of publications to individual FET projects in the sample,
2. to calculate citation rates for all FET related publications within a time window of 3 years after the publication date of the respective article, and
3. to determine an early relevant (highly-cited) publication and a late relevant (highly-cited) publication for each FET project. The early publication was needed to determine the level of novelty of the original FET idea. This was done in a separate deliverable, the LDA-analysis (D5). The late publication was needed to trace the impacts of the respective FET idea in academia and was in almost all cases the starting point for the citation analysis.

To identify relevant publications, we used a combination of data provided by the Cordis website maintained by the European Commission and data provided by the Web of Science (WoS) database which is maintained by private firm Clarivate Analytics (formerly Thomson Reuters). In fact, most publications were identified using the Web of Science database and a smaller share of the publications, especially Open Access publications, were included using Cordis. To identify the publications related to the set of FET projects we used the "Acknowledgement"-field and the grant number information provided in WoS.

In an attempt to complement the list of publications we have analysed the publication lists provided at the websites of the FET projects in our sample. Here, it turned out that some project websites have also listed publications which had no direct link to research carried out in the FET project. Other projects, especially older projects in our sample, did not have project websites any more. Most importantly, the formats in which publications were listed at the project websites turned out to be very heterogeneous which made it impossible to automatically extract and include them in our internal database.

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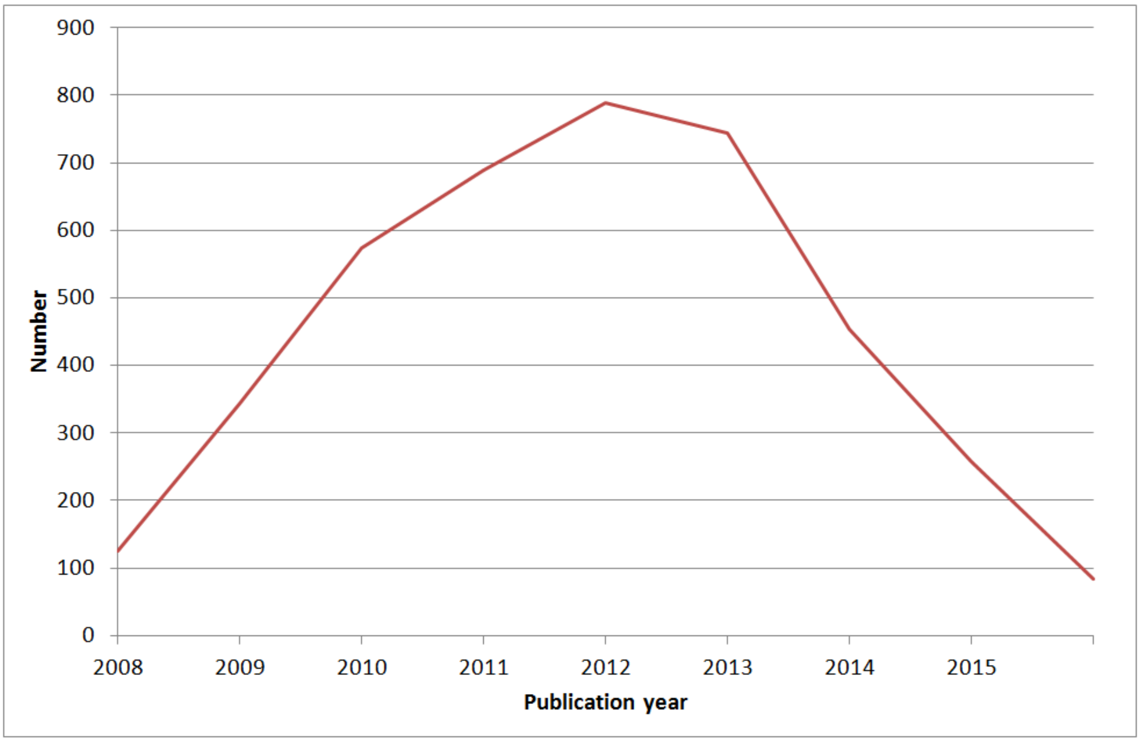
1 The sample covers FET Open and FET Proactive projects finished between 2007 and 2014. For a detailed sample description see D4.2 "Level 1 analysis", p. 2ff.

Due to the high number of entries, it was not possible to do this manually. As a result, we did not include publication lists from project websites in our pool of relevant publications.

However, the analysis of publication lists provided at the project websites allowed for an important insight: It became clear that in some cases, conference proceedings outweighed traditional journal articles in the publication lists by far. Yet, conference proceedings are very rarely documented in the Web of Science database. In fact, in our internal database we only count for 47 proceedings, most of these entries were collected form the Cordis Website. Proceedings that *are* listed in WoS do not provide acknowledgement information, which made it impossible to re-assign these to the individual publication lists. Conference proceedings are especially important in the field of informatics (computer science), a fact that challenges the significance of our findings and that will be discussed in more detail below.

Combining the WoS results and the Cordis results we have identified a total number of 4.063 publications which can be assigned to our sample of 224 FET projects in the publication period between 2008 and 2016. The distribution in time is shown in figure 1.

Figure 1: Analysed publications related to FET projects



Source: FET_TRACES 2017, based on Web of Science and Cordis publication data

In general, the number of about 4.000 publications seems quite plausible for a set of 224 research projects and it is a sufficient number for a bibliometric analysis seeking for representativeness. The major shortcoming is the low number of conference proceedings. From other bibliometric analyses we know that proceedings generally reflect early search results within a longer research process which are mooted. In general, proceedings are not highly cited. Thus, they rather reflect intermediate working steps and not final results in which several working steps are finally combined. Final results usually are published in journal articles. Therefore classic bibliometrics focuses on journal articles.

In informatics, conference proceedings play a more important role than in other research fields. In this fast moving field, most publications are presented at conferences and appear as proceedings. In the community of computer science researchers, proceedings are considered as equivalent to journal articles. Thus, if no proceedings are available for activities in informatics, major elements of the activities are missing. As various projects in FET comprise an important informatics element, the data set does not reflect informatics in an adequate way. The number of publications and subsequently the number of citations in informatics is generally too low compared to other scientific fields. We will hint to this shortcoming where ever it is relevant in the further course of this report. We have tried to counter this void to some extent in the case studies (Deliverable 9) in which we cover many computer science dominated projects.

Supposed all types of publications were available, a separate analysis of journal articles and proceedings would be necessary nonetheless, because citation rates of journal articles and proceedings considerably differ.

Due to the incomplete coverage of data from early FET projects, we have an unequal distribution of publications: 916 of the period from 2007 to 2010 and 3147 for 2011 to 2014. For the early projects, the number of documented publications per project is on average at a level of 9, for late projects at 26.

3 Results

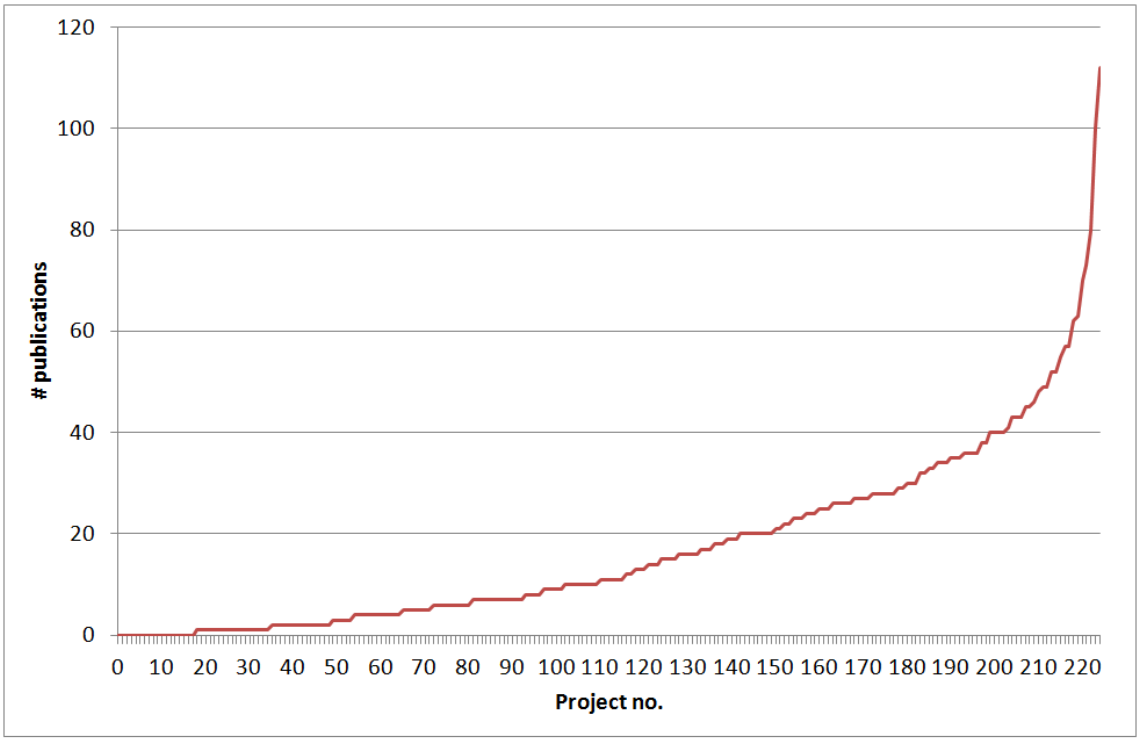
3.1 Publications

3.1.1 Number of publications per project

The bibliometric analyses was conducted for the data set in total and project by project. In the following we use these two perspectives to get a detailed impression of the activities carried out in the context of the FET programme.

We start with the individual project perspective. Figure 2 displays the number of publications per project, whereas projects are not displayed by their acronym but are numbered on the x-axis. (1-224). The distribution shows that for 17 projects, no publications were recorded at all. In many cases, the number of publications is below 20. This may be due to the fact that conference proceedings are captured insufficiently in our database. In addition FET projects conducted in the early phase of our sample (2007-2010, mostly FP6) are less well documented than those of the more recent phase (2011-2014, mostly FP7).

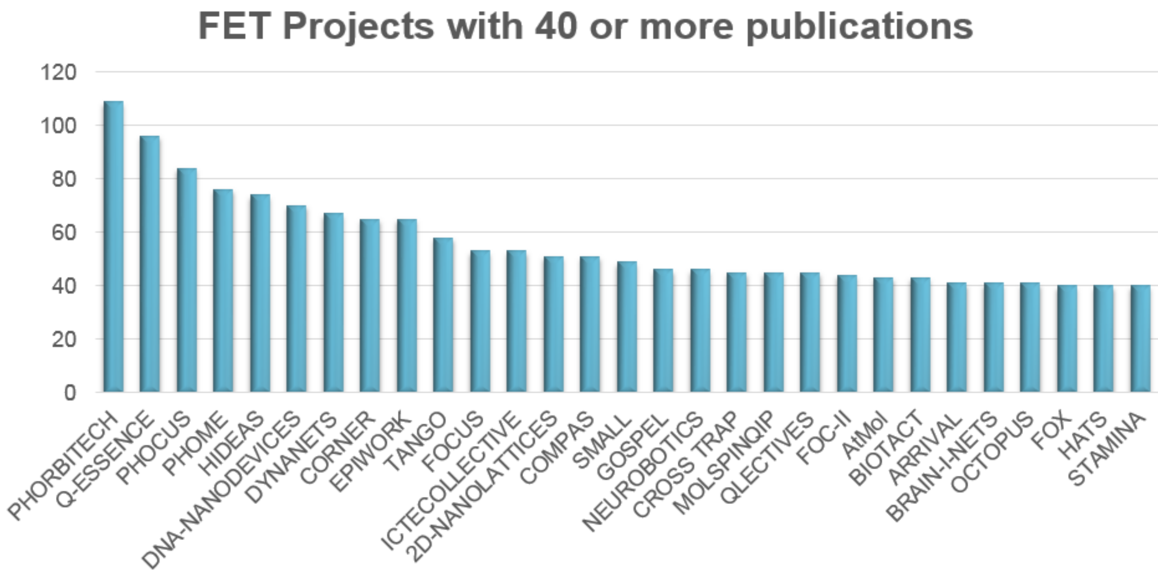
Figure 2: Number of publications per project in the FET programme



Source: FET_TRACES 2017, Web of Science, own compilations

Figure 3 shows the FET projects with the highest number of publications in our sample. The output of publications from these projects has been between 40 to 112 each.

Figure 3: Top-publishers: FET projects with more 40 or more publications



Source: FET_TRACES 2017, Web of Science, own compilations

The average number of publications per project is 20. As the project consortia consisted of 5 teams on average, the number of 20 publications per project is within the range of reasonable expectations. These imply 4 publications per participating team.

3.1.2 Scientific fields covered by FET-projects

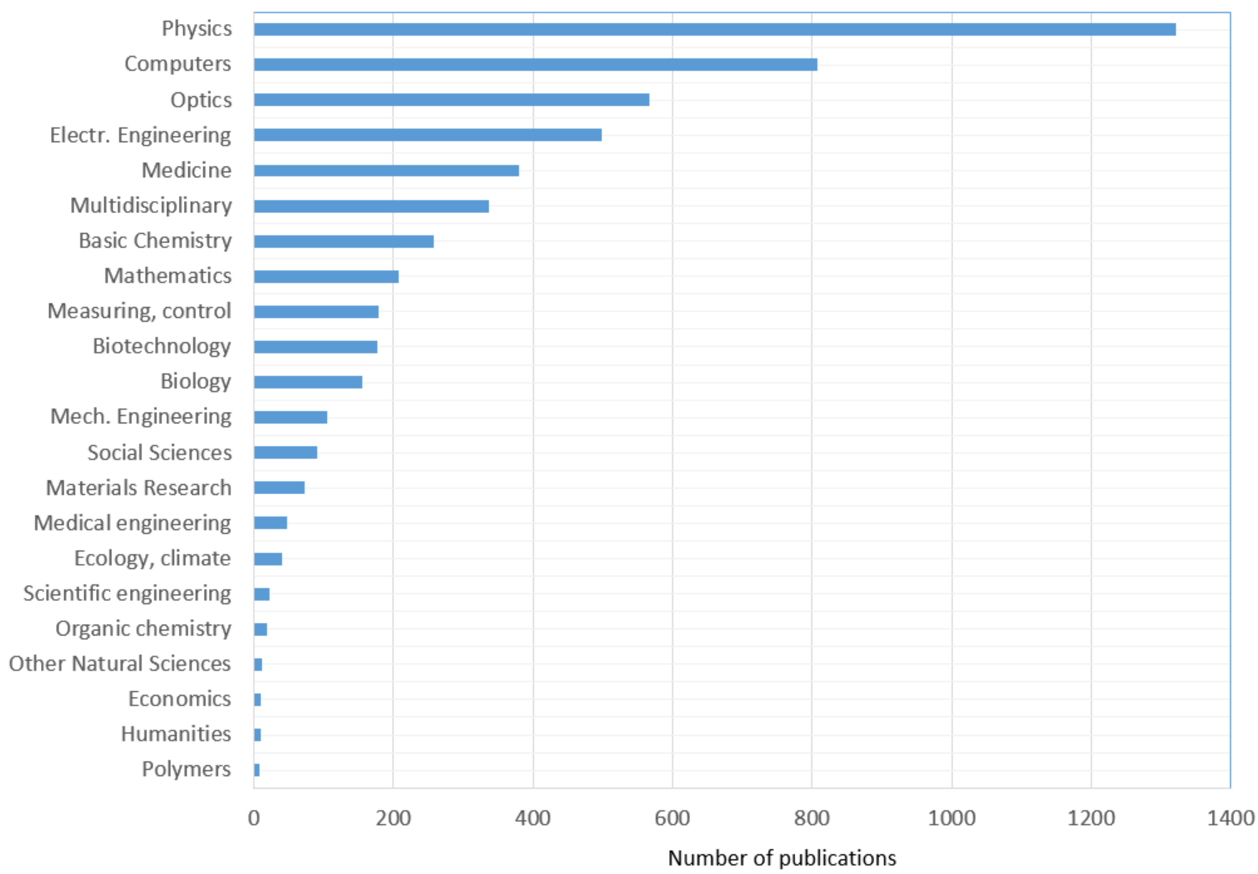
The following results refer to the data set in total. The publications in our data set allow for an assessment in which fields of science the FET programme is active. For this purpose we have aggregated the 242 subject categories of WoS into 27 scientific fields.[2]

2 “Subject categories” refer to the journals in which the article was published. The identified publications were thus classified according to the journal classification(s).

According to this classification, FET projects cover all fields of science, however, with a dominant role of physics (figure 4). On a lower level, the fields computers, optics, electrical engineering, and medicine follow.

Figure 4 shows the wide spectrum of scientific disciplines to which FET projects have contributed new insights. In fact, figure 4 shows a first version of “output interdisciplinarity” which we have defined in the indicator report (D3) as "Number of projects with publications in different subject areas in the Web of Science." Figure 4 shows in which disciplines the output of FET research is being classified. Highly cited publications have a greater weight here, because the citing publications were used for the disciplinary classification. Publications in different disciplines lead to citations in different disciplines.

Figure 4: Fields of activity of FET projects (Top 22)



Source: FET_TRACES 2017, Web of Science, own compilations. Other fields of activity are Geosciences (4 publications), Pharmacy (2), Chemical engineering (2), Nuclear Engineering (2), and food, nutrition (1)

As explained above, computer sciences are underrepresented in our data set of publications. It is quite reasonable to assume that its weight is higher and that it is even equivalent to the weight of physics in our sample.

One of the reasons for the high relevance of Physics might be that physicists have special access to new scientific developments and are thus very well suited for FET-like research. In contrast, engineers as well as computer scientists tend to apply existing insights, having less direct access to basic new principles and models.

Interestingly, the fields of activity found in the bibliometric analysis match the results of the portfolio analysis (D 4.2). In the portfolio analysis, FET projects were assigned to 12 different topics, ranging from “Unconventional Devices” to “Practices and Communities”. We found that most of the FET projects in our sample belong to the “Unconventional devices” topic, followed by "Quantum and Photonics”. Referring to our bibliometrics results it seems that physicists are needed not only in the "Quantum and Photonics” cluster but also in the “Unconventional devices” cluster where foundational new principles are being applied to build concrete devices. Especially when it comes to applying new insights, interdisciplinary collaborations with engineers, medical scientists medicians etc. are needed.

3.1.3 High profile publications: Publications in *nature* and *science*

An indicator for high quality and outstanding relevance is the publication of research results in the journals *nature* and *science*. In our sample of publications, we have found 34 FET-related publications in *nature* and *science* form a total of 10 different projects in our sample (see table 2).

Table 2: Projects with publications in *nature* and *science*.

High impact scientific publications: Number of publications in nature and science

Project title	Nature/Science together	# Articles in Nature
BRAIN-I-NETS - Novel brain-inspired learning paradigms for large-scale neuronal networks	4	2
AQUTE - Atomic quantum technologies	3	2
QIBEC - Quantum Interferometry with Bose-Einstein Condensates	3	0
PHOME - Photonic metamaterials	3	0
Q-ESSENCE - Quantum interfaces, sensors and communication based on entanglement	2	2
CONNECT Consortium of neuroimagers for the noninvasive exploration of Brain connectivity and tractography	2	1
NAME-QUAM - Nanodesigning of atomic and molecular quantum matter	2	2
MOLSPINQIP - Molecular spin clusters for quantum information processing	2	2
PICC - The physics of Ion Coulomb Crystals: Thermodynamics, Quantum control, and Quantum Simulators	1	0
PHORBITECH - A Toolbox for Photon Orbital Angular Momentum Technology	1	0

Source: FET_TRACES 2017, Web of Science, own calculations.

Contributions in *nature* and *science* usually have very high citation rates (see section 3.7 Expected citation rates)

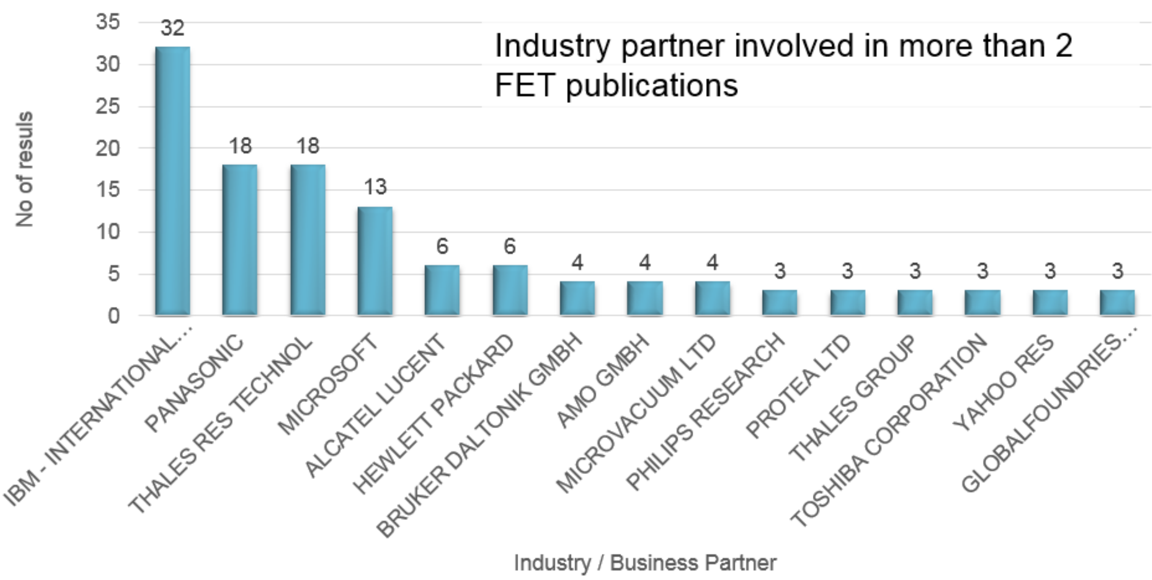
3.1.4 Industry participation in publications

As the FET projects aim at the generation of new technologies, the share of publications with the participation of authors from industry is an important characteristic. Of all publications in our data set, 182 had at least one author from industry, equivalent to 4.5 percent of all publications. Whereas the figure on the level of the programme seems relatively low, a different picture evolves when looking at the individual projects.

On the level of the individual projects we find that in 73 projects, at least one publication was written with the participation of an industrial partner. Taking the whole set of 224 projects as basis, this equals to 32.6 percent. Thus, in almost 33 percent of the FET projects in our sample, industry was at least partly involved in the dissemination of results. This finding can be assessed as a high level of cooperation.

Figure 5 displays the names of the companies which were involved in more than 2 FET publications thus showing the most active dissemination partners of FET projects with an industry relevance.

Figure 5: Top-participating companies: Industry participation in FET projects



Source: FET_TRACES 2017, Web of Science, own compilations

To some extent, co-publications with industry can be considered as "output industry relevance" of FET projects because the numbers relate to results and not to plans of research carried out in the context of specific FET projects. By contrast, the indicator “input industry relevance” tend to reflect the plans of the consortia to produce industry-relevant results. In our study, "input industry relevance" is measured as a share of industry participation in all FET projects which is 40% in our sample (see D4.2, p7ff). Compared to relatively high figure, 32.6% are lower than expected. The difference might reflect the fact that comanies are generally less interested in scientific publications than in technical developments which may lead to marketable products or services.

3.2 Citation rates

The main bibliometric parameter is the number of citations in a pre-defined timeframe. The parameter is called "observed citations". Observed citations indicate quality and relevance of the research carried out or started in FET projects: The more observed citations, the larger the footprint of FET-induced research within the scientific community.

Generally, the number of citations depends on the delay between the date of publication and the time of observation, as the number of citations increases with the length of the period after the publication. For making the citation scores of different years comparable, we only count the citations within the first three years after the publication. For each FET-related publication we defined a 3-years window and counted the citations of the respective publication within this time window. For example, for a FET article published in 2008 we counted the citations in the years 2008, 2009 and 2010.

The total number of observed citations is 24709. With a total of 4063 relevant publications in our sample, the average citation rate per publication is 6.1.

Our inhouse version of the Web of Science database only covered publications until the first half of 2016 at the time of the analysis. For the citation analysis, this means that the citation rates of publications until 2013 can be exactly determined (3-years window). Publications from 2014 and in particular those of 2015 have to be extrapolated. The citations of publications from 2016 cannot be determined in a reliable way. Therefore, the analysis of citations covers publications only until 2015.

Altogether, more recently finished FET-projects have a higher citation rate per publication (49 on average) than publications from earlier projects (average of 18 citations per publication) which mainly reflects the fact that more recent projects are better documented than the earlier ones.

Comparing citation rates of FET Open and FET Proactive projects it can be said that FET Open publications are more frequently cited than publications from FET Proactive projects. We calculated an average highest citation rate of 41,2 for FET open publications and 36,2 for FET Proactive publications.[3]

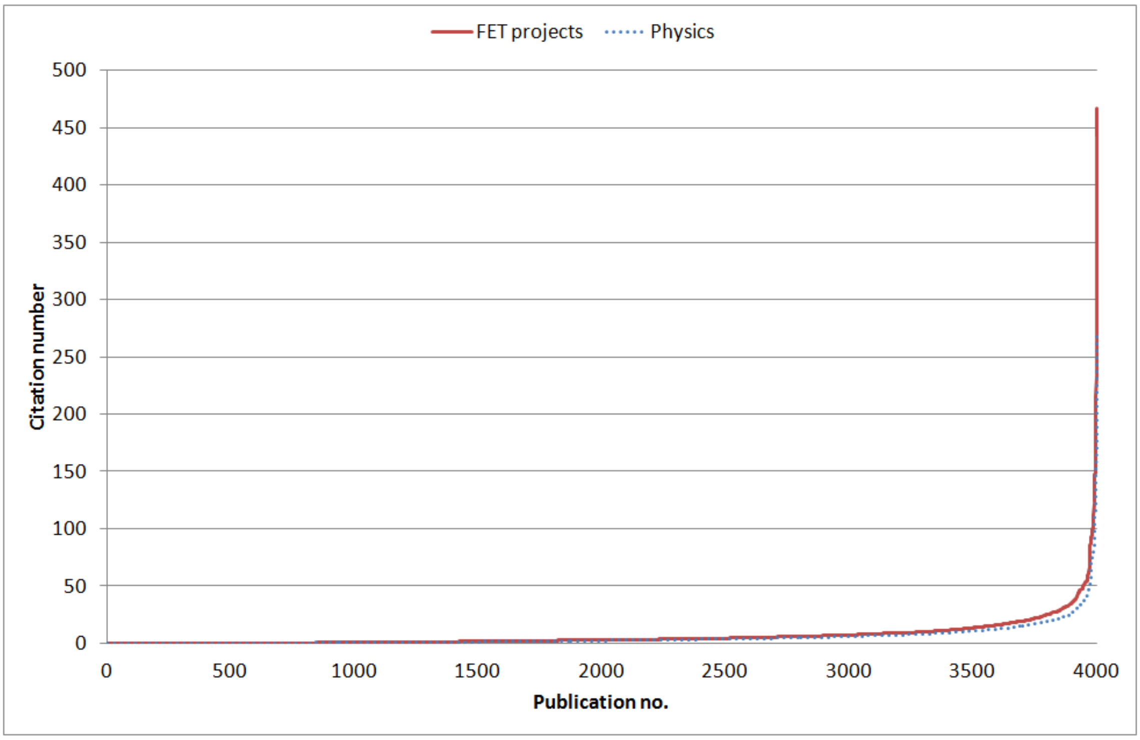
[3] For some projects in our sample, no publications could be detected, thus finally 124 FET Open and 75 FET Proactive projects were analysed. We used the highest cited publication from each project as a basis for the calculation of the average.

3.2.1 Comparison of FET-citation rates with physics-citation rates

It is difficult to assess whether citation levels are high or low, as the number of citations differ by scientific field. In the case of FET projects a majority is linked to physics. Therefore we selected physics as reference for FET publications. The citation scores in physics are relatively high, so that we can expect that physics is a very strong benchmark.

In figure 6 we can see a standard distribution of citation rates with many low scores linked to routine working papers and very few very high scores linked to exceptionally good and relevant papers. All in all, the distribution of the citations of 4.000 publications from the FET dataset and randomly selected 4.000 publications in physics are quite similar.

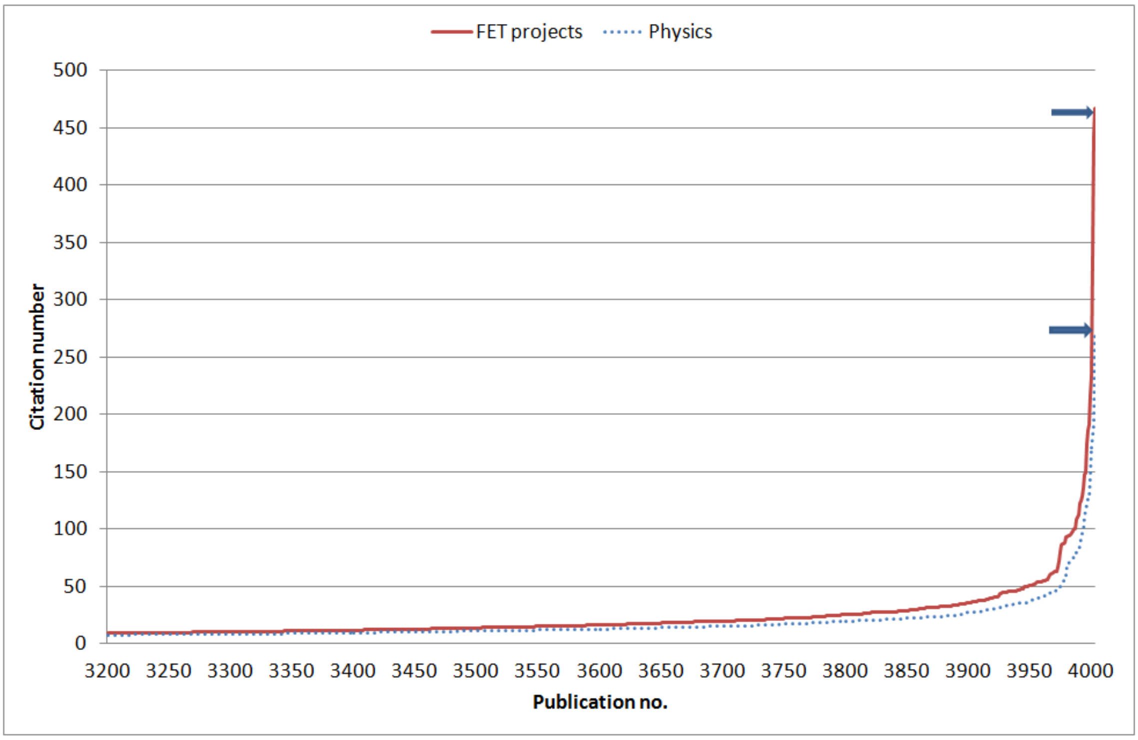
Figure 6: Number of observed citations of all FET-related publications and of physics-related publications



Source: FET_TRACES 2017, Web of Science, own compilations, using a 4.000-publications-sample from FET and physics. The exact number of "all" FET-related publications is 4.063.

Looking only at the top-800 publications, we can observe a higher level of observed citations for FET projects compared physics. This is highlighted in figure 7.

Figure 7: Number of observed citations of the top-800 publications showing more citations for FET-related publications than for comparable physics publications



Source: FET_TRACES 2017, Web of Science, own compilations

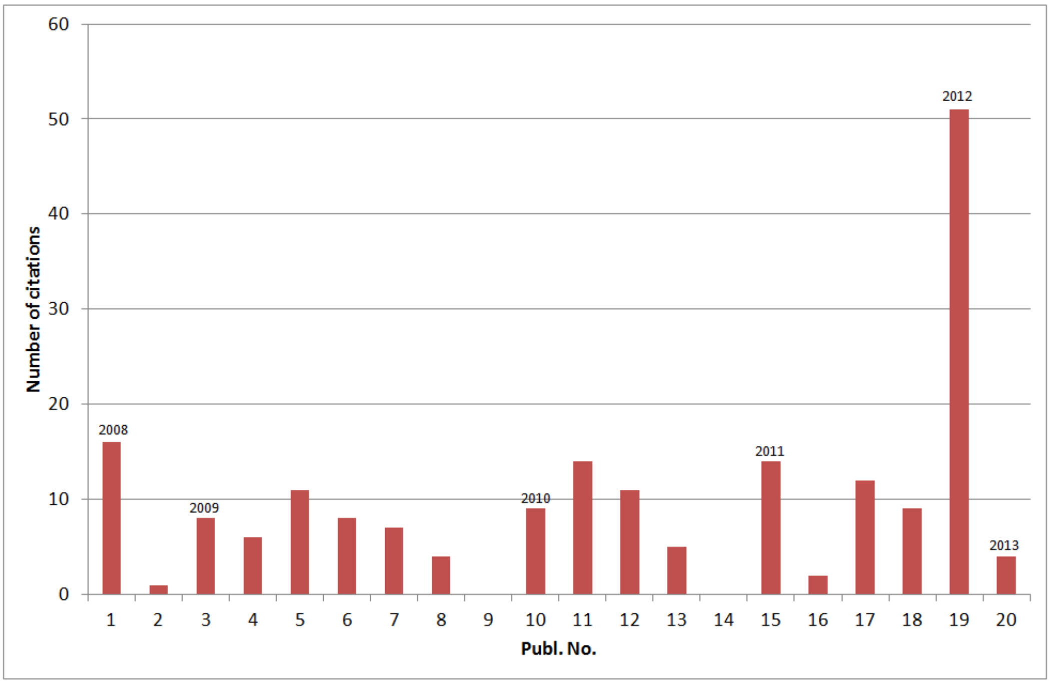
To summarize, the average citation score of publications of FET-related publications is very high and higher than the score in physics.

3.2.2 Citation rate patterns within individual projects

Our database of publications also allows for a project-by-project analysis. When looking at the citation scores of the individual publications of the different FET projects, we find an enormous variation from publication to publication: Some are highly cited, some are less cited, some are not cited at all. However, there are two typical distributions of the citation scores which are illustrated in figures 8 and 9. Both selected projects have about 20 publications.

In the first project (figure 8), we have one publication with a high citation score just at the beginning of the project and one with an extremely high citation score near the end. In between are publications with a low or medium citation level.

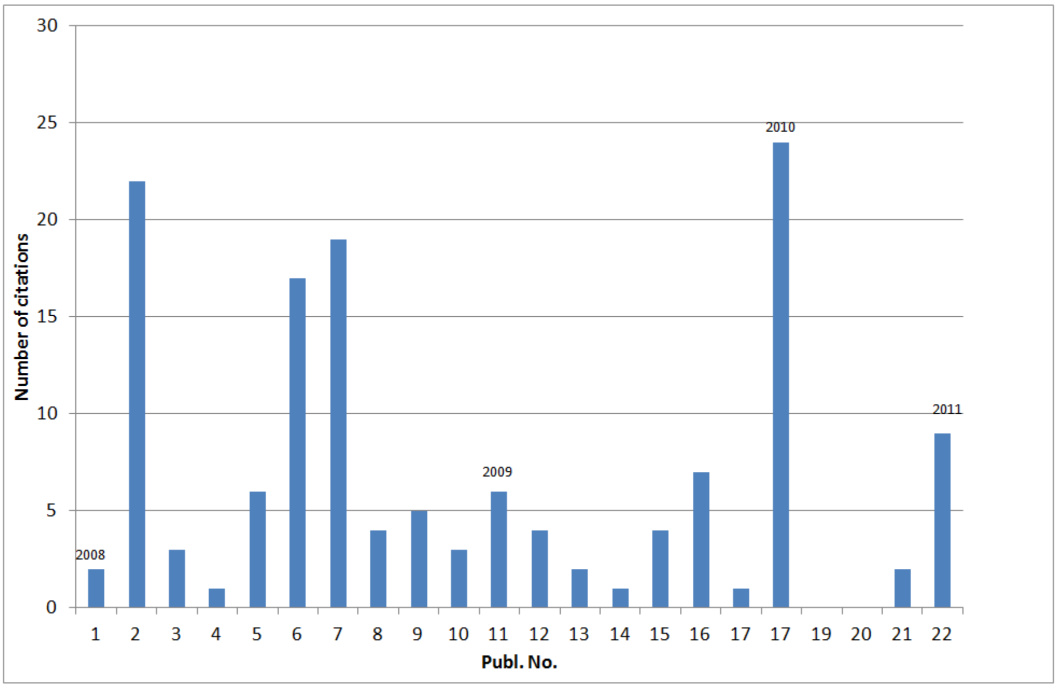
Figure 8: Publications by time and citation score within a first selected project



Source: FET_TRACES 2017, Web of Science, own compilations

In the second project (figure 9), there is again an early and a late highly cited publication, but the citations in between are relevant as well.

Figure 9: Publications by time and citation score within a second selected project



Source: FET_TRACES 2017, Web of Science, own compilations

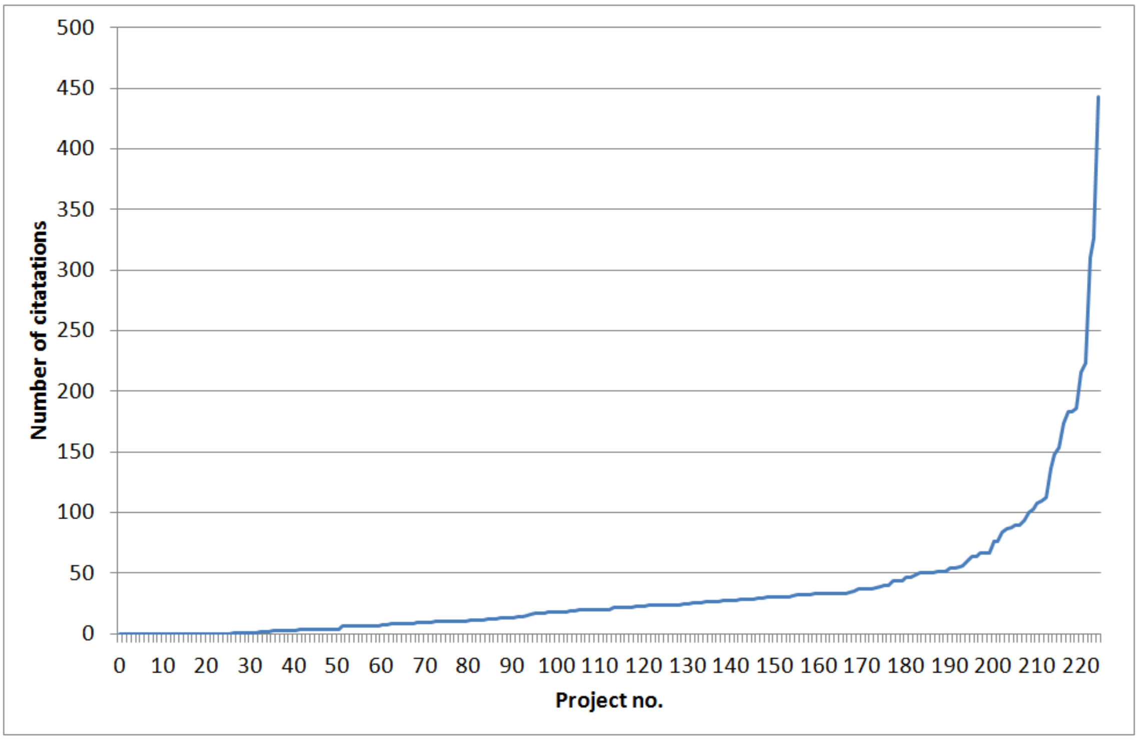
Obviously, there is often a publication at the beginning of the project describing the new findings where the project is build on and which shall be elaborated further by the project activities. And then there is a publication at the end of the project documenting the results of the combined intermediate steps which is again highly cited. In between there might or might not be publications with high citation scores depending on the relevance or novelty of the intermediate steps for the scientific community. However, publications referring to intermediate steps usually do not get citation scores as high as the early or later stage publications.

3.2.3 Citation rates of central FET publications in our sample

Determining the citation rate of every publication originating from a specific FET project allows us to identify the most important publication of this project. The most important publication is the publication with the highest citation score.

Analysing the highest citations per publication for each project we see the following distribution across our sample of 224 projects (figure 10):

Figure 10: Distribution of highest observed citations per FET project in our sample, physics-adjusted (3-years citation window)



Source: FET_TRACES 2017, Web of Science, own compilations

For the further analysis we focus on the publication with the highest citation per project. As mentioned above, different disciplines have specific citation cultures and thus their average number of citations differ. For example, the average citation rate of publications in physics within a three-years citation window is in the range of 5 and is similar to that in medicine. In contrast, the average citation rates in computer science or electrical engineering is in the range of 1.5. Thus, without correction, the citation scores in the latter fields would be underestimated in a sample also including publications in physics.

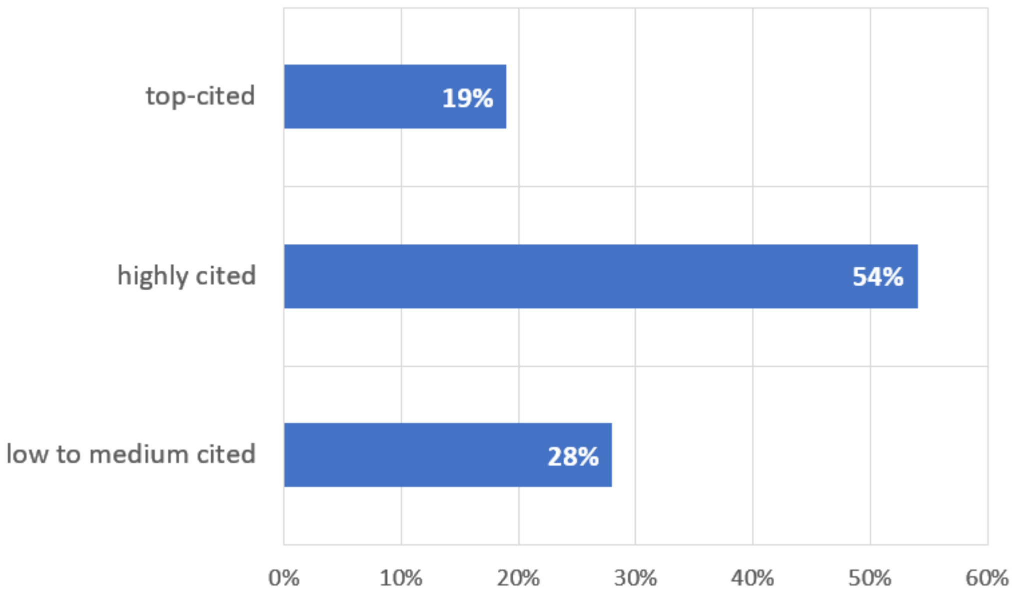
And in fact, the FET programme is such a sample including different disciplines. However, physics is the dominant field (see section 3.2). Therefore, the citation level of the other fields were adjusted to that of physics.

As figure 8 above shows, the range of the highest citations is between 0 and 443. In 120 projects, equivalent to 54 percent of the projects, the citation rate is equal to or higher than 20, in 42 projects, equivalent to 19 percent, the citation rate is equal to or higher than 50.

The highest citation rate of 443 was achieved by a publication in physics of 2012. The score was measured for a three years window for reasons of comparability with publications from other years. Without citation window, this special publication reached in June 2017 a citation score of 1220, thus a very extreme value.

As the average citation rate in physics is 5, the citation rate of 20 is four times higher than the average, the citation rate of 50 ten times higher. Thus a score of 20 represents successful projects, the score of 50 extremely successful projects.

Figure 11: Overview of citations of FET publications based on highest observed citations per FET project, physics-adjusted, 3-years citation window



Source: FET_TRACES 2017, Web of Science, own calculations. Figure based on same numbers as figure 10.

Table 3: Numbers to figures 10 and 11: Overview of citations of FET publications

	Number of citations	Percentage	Number of projects (n=224)
top-cited	>=50	19	42
highly cited	>=20	54	120
low to medium cited	<20	28	62

High-risk is a major requirement of FET projects and uncertainty a main attribute of emerging technologies according to Rotolo et al. (2016). Therefore it is possible to compare the risk distribution in the risk-oriented research to that of the risk-oriented investments in venture capital. In venture capital investments, a typical value distribution of the results can be observed: About 10 percent of the investment projects fail, 20 percent fail partially, 50 percent are successful but the results are average, 10 percent have results distinctly above average and only 10 percent are extremely good (see, e.g., Sahlmann 1990:484, Cochrane 2005, Mason et al. 2002).

As in the analyzed FET-projects, 54 percent of the projects achieve citation rates above 20 and 19 percent citation rates above 50, the share of successful projects surpasses the expectations of risk investments. In any case, the attribute of uncertainty or risk means that many cases will not be successful, but that a small share of the cases is extremely successful and justifies the investments in this type of research.

This comparison of investment projects and research projects assumes that high citation scores equal success. On a conceptual level, this is quite a reasonable assumption. However, there are other aspects defining "success" as well. For example, highly cited project results may only be the first step in the actual transformation of research results into useable technologies or marketable products.

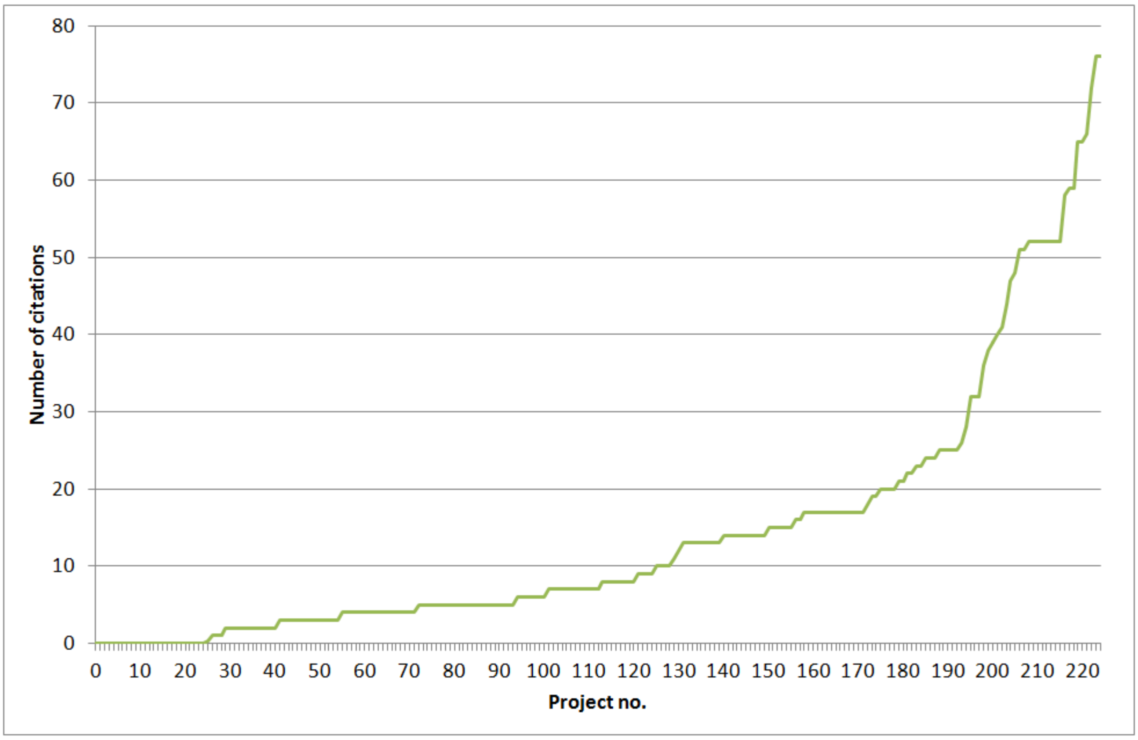
3.2.4 Expected citation rates of FET-projects

A further revealing bibliometric indicator is the journal-specific expected citation rate of FET publications. This indicator reflects the scientific quality of the journals where the publications are released.

The results documented in Figure 12 show that in 61 projects, equivalent to 27.2 percent, are released in high quality journals with an expected rate of between 20 and 50. In 27 projects, equivalent to 12.1 percent, very high values above 50 are achieved. Some publications have expected rates with very high values. An expected citation rate of 23 refers in one case to a publication in NANO LETTERS, in another case the value of 56 to a publication in SCIENCE, the highest value of 76 by NATURE. This result confirms the expectation that publications in highly ranked journals generate high citation scores (see section 3.3 Publications in high-profile journals)

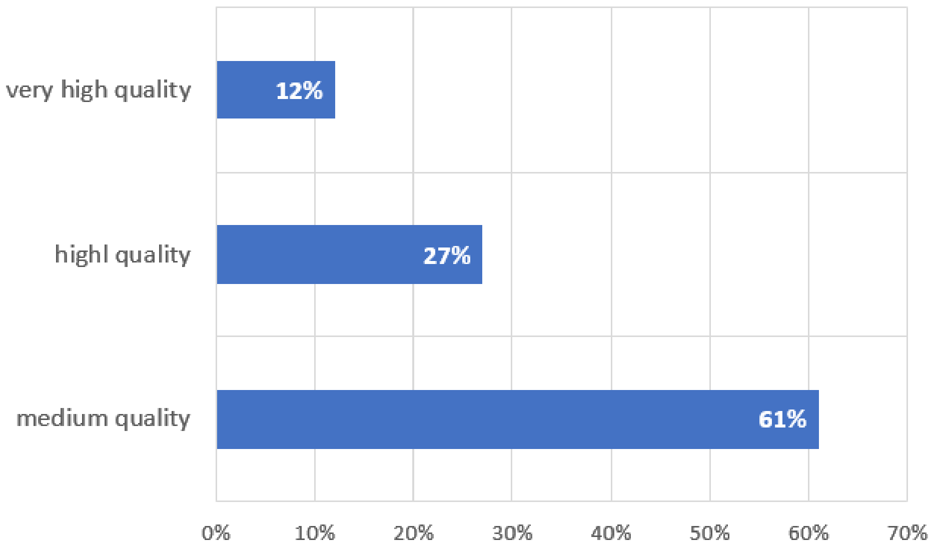
Again, a typical distribution of high-risk research is found where about 10 percent (here: 12 percent) of the projects achieve excellent results.

Figure 12: Highest expected citation rates per project



Source: FET_TRACES 2017, Web of Science, own compilations

Figure 13: Overview of journal-specific expected citation rates per project



Source: FET_TRACES 2017, Web of Science, own calculations. Figure uses same numbers as in figure 12 above.

Table 4: Numbers to figures 12 and 13: Overview of journal-specific expected citation rates per project

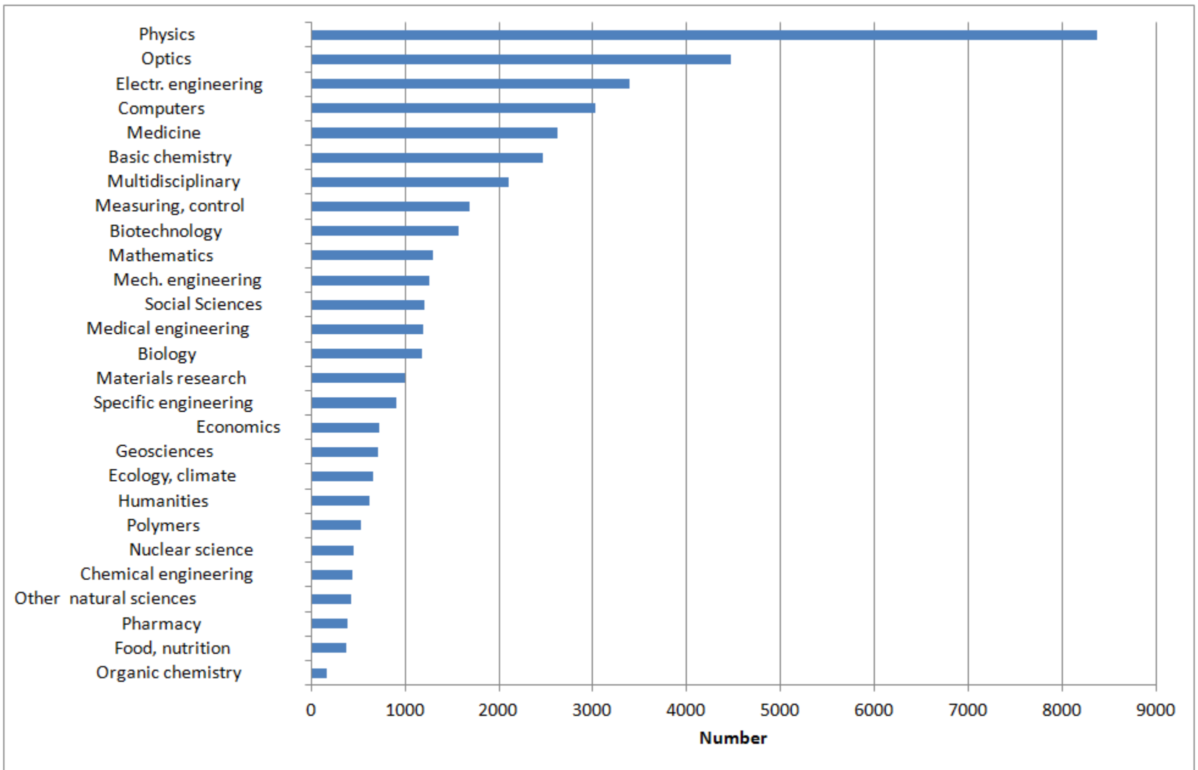
	Journal-specific expected citation rate	Percentage	Number of projects (n=224)
very high quality journals	>50	12	27
high quality journals	20-50	27	61
low to medium quality journals	<20	61	136

3.2.5 Impact of FET-projects on other scientific fields

A further aspect is the impact of FET projects on other scientific activities. This can be represented by displaying the scientific fields of the publications which cite publications of FET projects. The basis for this analysis are the citations of all FET publications in our database whereas the highly cited publications naturally contribute with a higher weight. As main result, the distribution of the fields of activity is largely corresponding to the scientific fields in which FET projects usually are active in (figure 10). Again, the impact on computer science is underestimated.

As specific finding is that the impact of fields of lower activity in FET such as polymers, geosciences, economics or pharmacy on these fields is considerable.

Figure 14: Fields of impact of FET projects



Source: FET_TRACES 2017, Web of Science, own compilations

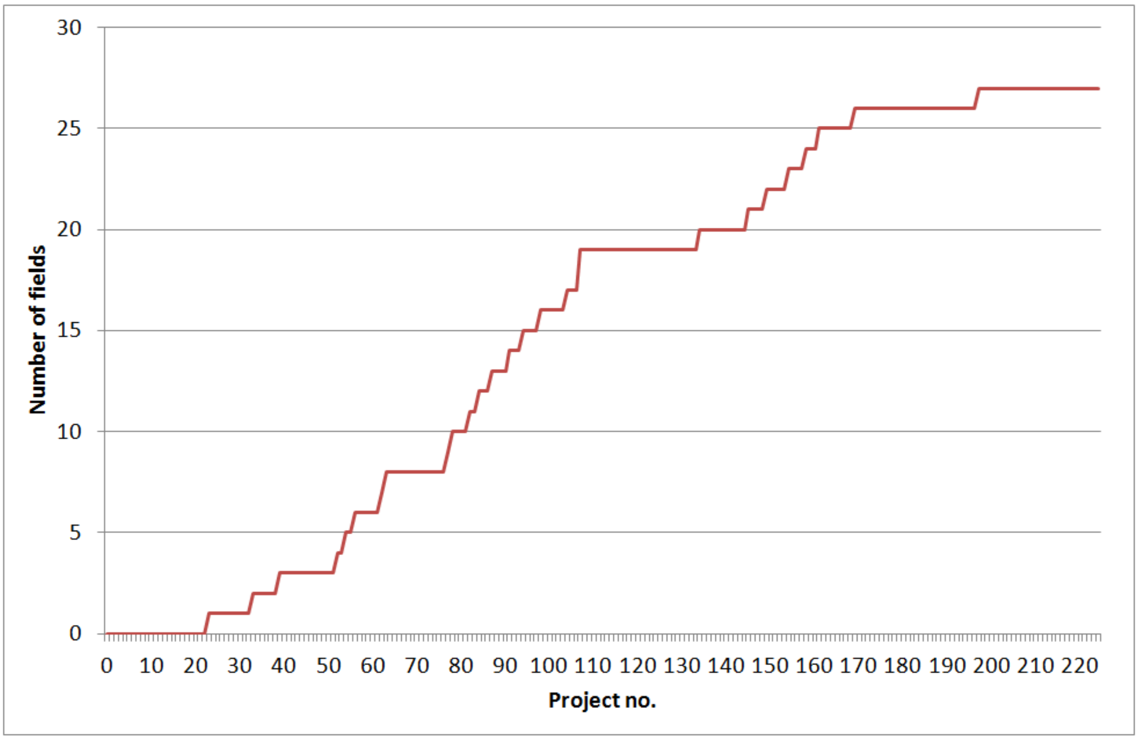
3.2.6 Interdisciplinarity: Contributions of FET-projects to other scientific fields (stretch)

An important requirement of FET projects is interdisciplinarity. In this section we analyse the contributions of FET projects to other scientific fields. In contrast to the above section which has the total number of citations as a basis, here we look at citations of publications of individual FET projects.

For capturing the footprint of FET publications, we count the scientific fields in which FET publications were cited in. This is done in the same manner as in section 3.1.2 "Scientific fields covered by FET projects" where we counted the scientific fields of the publications. Here we count the citations assigned to these publications. We do this by using our own scientific field pattern which consists of 27 scientific fields and which is an aggregation of the 242 subject categoies of the WoS. For each publication citing a FET publication we determined the respective scientific field. As a basis we again used all FET related publications.

The number of fields citing FET publications characterises the wideness of fields which are reached by the FET project outcomes. In principle, the highest possible level of fields is 27, reflecting a very broad impact of a project on many fields of science. The distribution of the number of fields per project is shown in figure 15.

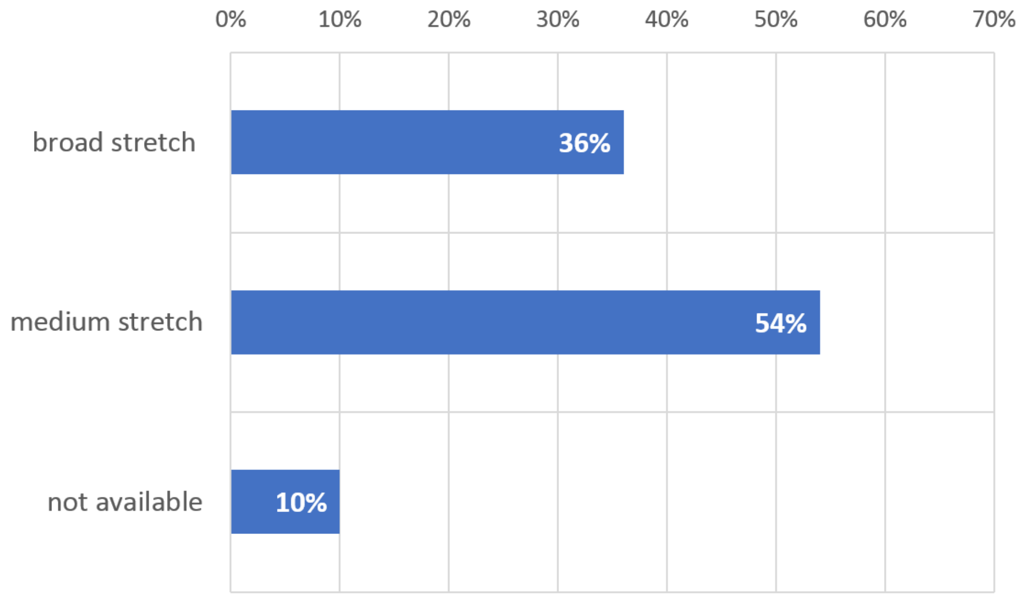
Figure 15: Number of fields of the citing publications per project (stretch)



Source: FET_TRACES 2017, Web of Science, own compilations

According to this criterion, 80 projects, i.e., 36 percent, have an impact on more than 20 scientific fields, thus they have a broad impact on more than 80 percent of the scientific fields.

Figure 16: Overview of the number of fields of the citing publications per project (stretch)



Source: FET_TRACES 2017, Web of Science, own calculations. Figure uses same numbers as in figure 15 above.

Table: Numbers to figures 15 and 16: Overview of number of fields of the citing publications per project

	Number of fields	Percentage	Number of projects (n=224)
Broad stretch on other scientific fields (stretch)	>20	36	80
Medium stretch on other scientific fields	<20	54	122
not available		10	22

3.2.7 Examples of scientific stretches of FET results

To get an impression which fields of science co-operate in FET projects, the main impact fields per project were identified, as the impact fields proved to be more sensitive than the activity fields (as shown in figure 4). "Main impact fields" are the research fields or disciplines which are most frequently citing FET related publications. Basis are again the citations of all FET related publications.

If the weight rate[4] was lower than two, all respective fields were included. The situation in the FET programme can be described by the co-operations of the three fields physics, computer science (informatics, hardware) and medicine. In the case of physics, co-operations according to table 5 are found.

Table 5: Main co-operations of **physics** with other fields of science

Field	**Abs. number**	**Percent**
Optics	37	39
Basic chemistry	23	24
Electr. engineering	11	12
Single	10	11
Informatics	6	6
Biotechnology	5	5
Medicine	3	3
Total Physics	95	100

According to this type of analysis, physics primarily co-operates with optics and basic chemistry. Further co-operations can be found with electrical engineering, computer science, biotechnology and medicine. In particular, the co-operation with medicine and

4 Weight rate means the quotient of first and second field. For example, if physics has the value of 20 and optics 18, the weight rate for the individual project is 1,11.

biotechnology is remarkable. In some cases, the activity in the project is largely dominated by physics. These cases are labelled as ‘single’.

The co-operations in the case of computer science are documented in Table 6.

Table 6: Main co-operations of **computer science** with other fields of science

Field	**Abs. number**	**Percent**
Electr. engineering	47	56
Single	14	17
Physics	6	7
Mathematics	6	7
Biotechnology	5	6
Medicine	3	4
Control	3	4
Total Computer Science	84	100

Main fields of co-operation of computer science are electrical engineering, physics, mathematics, control, but also biotechnology and medicine.

The main co-operations of medicine are listed in table 7.

Table 7: Main co-operations of **medicine** with other fields of science

Field	**Abs. number**	**Percent**
Biotechnology	10	48
Social sciences	5	24
Informatics	3	14
Physics	3	14
Electr. engineerig	3	14
Med. engineering	3	14
Mech. engineering	3	14
Single	1	5
Total Medicine	21	100

The co-operation of medicine with biotechnology is self-evident. However, the co-operation with social sciences is less obvious. Noticeable are the frequent co-operations of medicine with various other fields of science.

3.2.8 Low level and high level interdisciplinarity

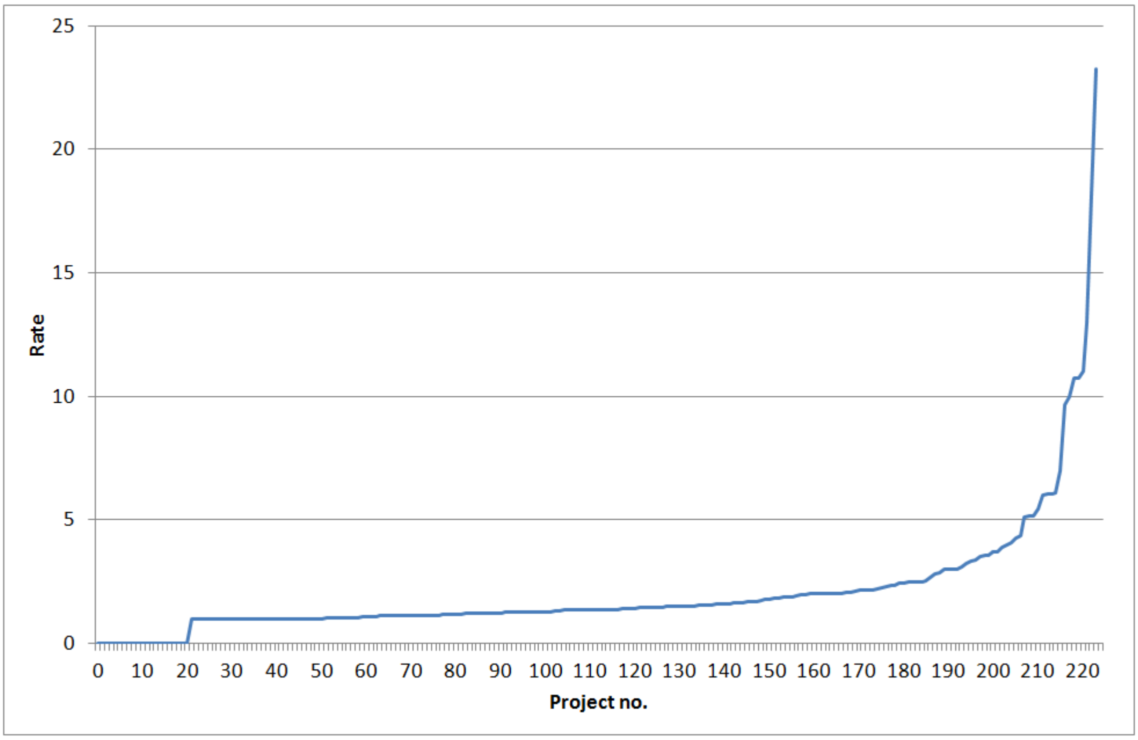
Real interdisciplinarity requires the co-operation of at least two disciplines on an equal or similar level. If one discipline dominates the others, the interdisciplinarity level of outcomes can be expected to be rather low. For determining the level of interdisciplinarity, we use the numbers of the most important citing field and the second one. The difference between these two numbers reflects the intensity of coherence between the contributions of both fields. E.g., if one discipline dominates the citing publications and the other fields are on a much lower level, a low level of interdisciplinarity can be assumed. If at least the two most important fields are on a similar level, close cooperation and thus a high level of interdisciplinarity can be assumed. If the ratio between the highest and second highest impact

$r = impact_1/impact_2$

is 1, both fields are on the same level. If the rate is largely above 1, the level of real co-operation between two fields is limited. The distribution of r according to Figure xx shows that in 10 percent of the cases, the r value cannot be determined (value=0). In the majority of the cases (68 percent), r is below 2, so that real interdisciplinarity can be assumed.

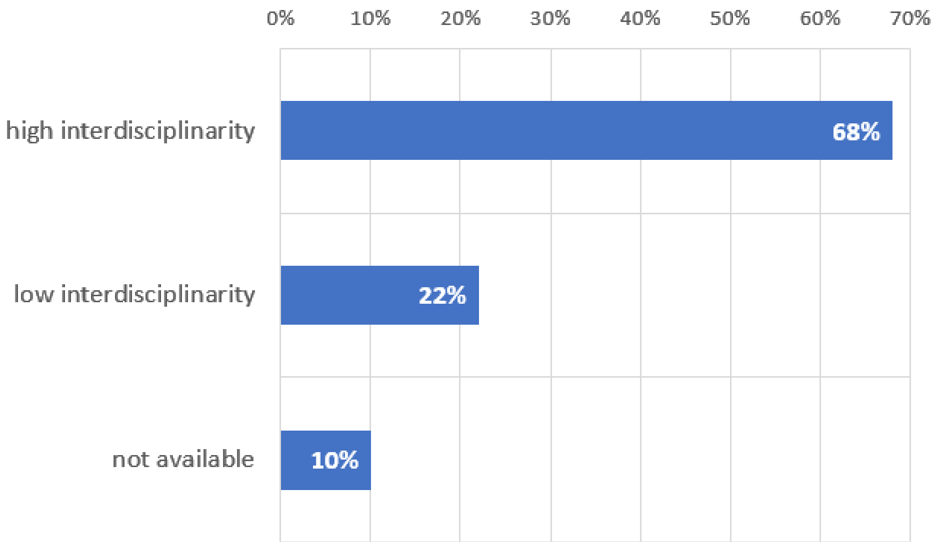
This could also be termed "Output Interdisciplinarity Plus" as not FET related publications but their respective citation rates are counted.

Figure 17: Rate of the number of citations to the first and second frequent field



Source: FET_TRACES 2017, Web of Science, own compilations

Figure 18: Overview of citations to the first and second frequent field



Source: FET_TRACES 2017, Web of Science, own calculations. Figure uses same numbers as in figure 17 above.

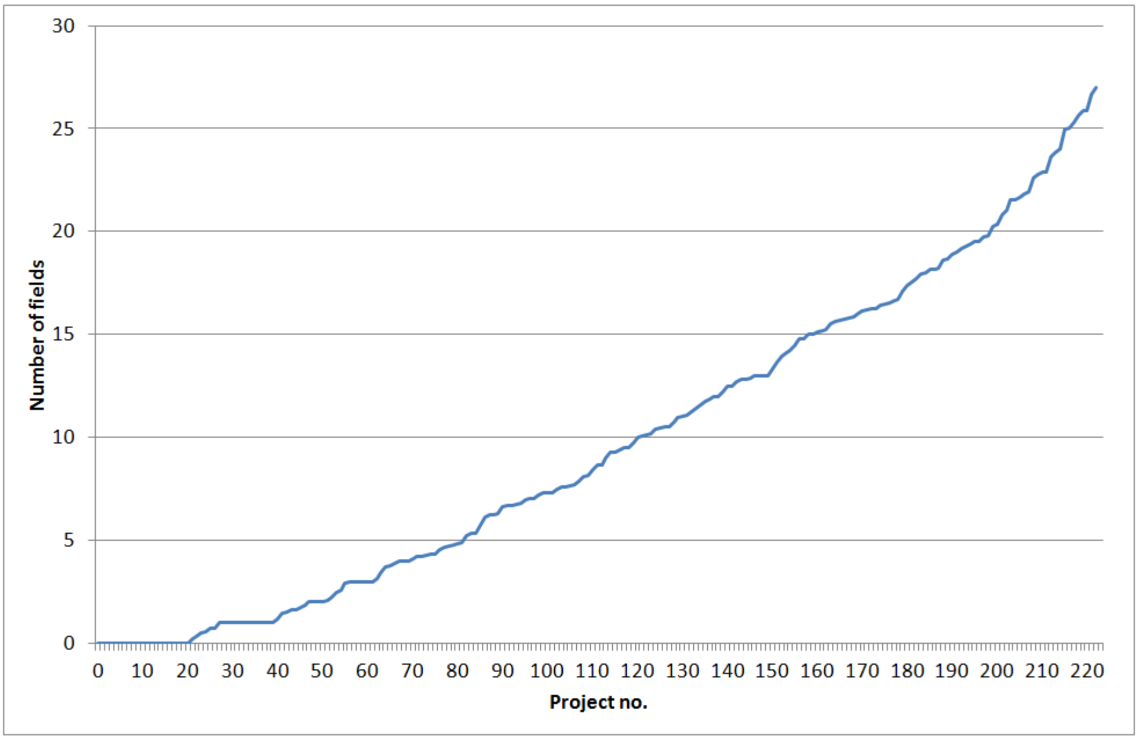
Table 8: Numbers to figures 17 and 18: Overview of citations to the first and second frequent field

	r	Percentage	Number of projects (n=224)
high interdiscipli-narity	r<2	68	153
low interdiscipli-narity	r>2	22	49
not available		10	22

3.2.9 Publications in a variety of scientific fields: Broad stretch and high level of interdisciplinarity

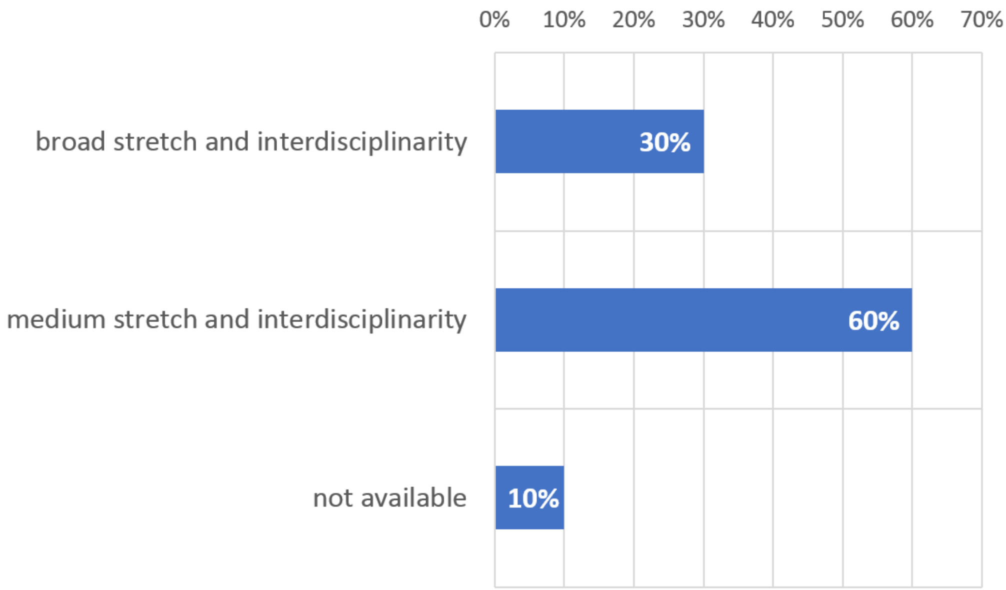
It is possible to calculate a weighted number of fields per project by dividing the number of fields by the ratio r. Even then, 67 projects, equivalent to 30 percent, achieve high levels of more than 15 fields (figure 19). Thus a large share of FET projects fulfils the criterion of real interdisciplinarity.

Figure 19: Weighted number of fields per project (stretch and interdisciplinarity)



Source: FET_TRACES 2017, Web of Science, own compilations

Figure 20: Overview of weighted number of fields per project (stretch and interdiscipli-narity)



Source: FET_TRACES 2017, Web of Science, own calculations. Figure uses same numbers as in figure 19 above.

Table 9: Numbers to figures 19 and 20: Weighted number of fields per project (stretch and interdisciplinarity)

	r	Percentage	Number of projects (n=224)
broad stretch and interdisciplinarity	>=15	30	67
medium stretch and interdiscipli-narity	<15	60	135
not available		10	22

3.2.10 Congruence of criteria

By using bibliometric methods we have highlighted three dimensions of success for FET projects:

1 The uptake of new concepts in science in general (impact in terms of observed citations)
2 The uptake of new concepts by industrial R&D (number of co-publications with partners from industry)
3 The uptake of new concepts in other fields than it originally emerged (weighted number of fields)

In fact, these criteria have different orientations and are not necessarily congruent. Looking at the first forty projects according to each of these criteria, we find a coincidence of all three criteria (citations, industry and other fields) only for three of the projects (table 10).

Also the congruence in two criteria is relatively low. This means that a high performance in science does not necessarily imply a high performance in industry co-operation or a high performance in science does not necessarily imply a high performance in field coverage.

Nevertheless, the criterion ‘citations and other fields´ applies to 8 projects which shows that high relevance for the academic community in general and high relevance for other disciplines may go well together in some cases.

Table 10: Congruence of criteria for the 40 top ranked projects in three success factors

Criterion	**Cases of congruence**
Citations and industry	6
Industry and other fields	7
Citations and other fields	8
Citations, industry and other fields	3

This means that:

- Of the 40 highest cited projects, 6 projects also have an industry relevance,
- Of the top 40 industry relevant projects, 7 projects are also relevant for research in other scientific fields, and
- Of the 40 highest cited projects, 8 projects are also relevant for research in other scientific fields.
- Only 3 projects have succeeded the balancing ultimate to be present in the list of the top citation-projects, the top industry relevant projects as well as the top 40 projects being of high relevance for research in other scientific fields

In summary it can be said that according to the quantitative data congruence is not often achieved, but it can in fact be found in some cases.

4 Summary

To summarize, the FET projects generally achieve very good results in various dimensions, in particular in terms of (observed) citation rates, in terms of the articles published in high-quality journals, in terms of the level of interdisciplinarity and with some restrictions in terms of the share of publications with authors from industry.[5]

All in all, the bibliometric analysis confirms that the core targets of the FET program are achieved through the FET projects and that the results outperform the expectations.

By using bibliometric methods we have highlighted three dimensions of success for FET projects and thus for the characterization of emerging technologies:

1 Scientific excellence / Novelty: The uptake of new concepts in science in general (impact in terms of observed citations)
2 Interdisciplinarity: The uptake of new concepts in other fields than it originally emerged (weighted number of fields)
3 Starting innovation eco-systems: The uptake of new concepts by industrial R&D (number of co-publications with partners from industry)

The FET projects in our sample show impressive results concerning “scientific excellence”, “interdisciplinarity” and “starting innovation eco-systems”. Of course, not all impact dimensions can be covered by all projects alike. Rather, there are projects with extremely high citation rates, projects with very high impacts on other disciplines and projects with very high relevance for industry. Although not of the highest relevance, we even found projects which perform extremely good in two or even three of these impact dimensions.

This report documents the results of the bibliometric analysis which is related to a specific set of indicators (see introduction and Annex 1). For a full analysis of impacts according to our overall impact dimensions, the results of the other methods (portfolio analysis, survey, case studies) have to be considered as well. In this report, we have done this only in certain cases, for example when comparing input industry relevance

5 A methodological constraint of the bibliometric analysis of FET projects is the limited presentation of conference proceedings in our dataset. As conference proceedings are considered to be the main vein for disseminating research results in the field of computer science, this shortcoming is to some extent limiting the significance of our analysis. However, we applied a specific weighting to our internal list of top-40-projects which we used to select the case study projects.

(from portfolio analysis) and output industry relevance (co-publications with industry) in section 3.1.4 Industry participation in publications. However, a full picture of impacts will only evolve when assigning all results to the whole set of indicators. This will be done in Deliverable 8.1 “Results linked back to indicators”.

5 Literature

Cochrane, John H. (2005): The risk and return of venture capital. In: Journal of Financial Economics 75 (2005) 3–52.

Rotolo, D.; Hicks, D.; Martin, B. R. (2015): What is an emerging technology? In: Research Policy 44(10), 1827-1843.

Sahlman, William A. (1990): The structure and governance of venture-capital organizations. In: Journal of Financial Economics, 1990, vol. 27, issue 2, 473-521.

Mason, Colin M., Harrison, Richard T. (2002): Is it worth it? The rates of return from informal venture capital investments. In: Journal of Business Venturing 17 (2002) 211–236.

Annex 1: Indicators covered in the bibliometric analysis

Numbers indicate sections in D3 where these indicators are described in more detail.

Methods	Indicators
Bibliometrics (lead: ISI)	Relevance I: Number of scientific publications originating from a FET project (publication lists as assigned by Eupro-database are documented in the portfolio-analysis) 321
	High impact scientific publications: Number of FET publications in nature and science (bibliometrics) 3018
	Relevance II: Publications with industrial partners (survey and bibliometrics) 322
	Input interdisciplinarity: Number of projects with partners from different scientific fields. Not covered in our study. Having different disciplines in the project is a success criterion for FET projects. An examination of a sample of projects as to their level of input interdisciplinarity was carried out in the Observe project. It tuned out that most project displayed a medium level of interdisciplinarity. Taking into account the results from the citation analysis in this deliverable it is reasonable to assume that there is no casual relation between input and output interdisciplinarity. However, it might be worthwhile to follow-up on this issue in a special analysis. 3111 Output interdisciplinarity: Number of projects with publications in different subject areas in the Web of Science 3112
	Community building I: Transfer of new ideas into the scientific and industrial R&D community - Number of citations of FET-project related publications. 323
	Community building II: Dissemination of a new ideas and the genesis of new scientific communities - Number of FET-related publications co-authored by researchers who were not involved in the original FET project (see survey,

	not available from Eupro-data) 324
	Dissemination of FET ideas into industry: number of publications that are co-authored by researchers from industrial R&D not involved in the original FET project (see survey, not available from Eupro-data) 325
	Communicating FET results to industry: Number of contributions to proceedings of conferences with industry involvement (not available from Eupro-data) 328
Project families (lead: AIT)	Project families analysis: Number of FET projects which triggered other research proposals (survey, not available via Eupro bibliometrics) 327