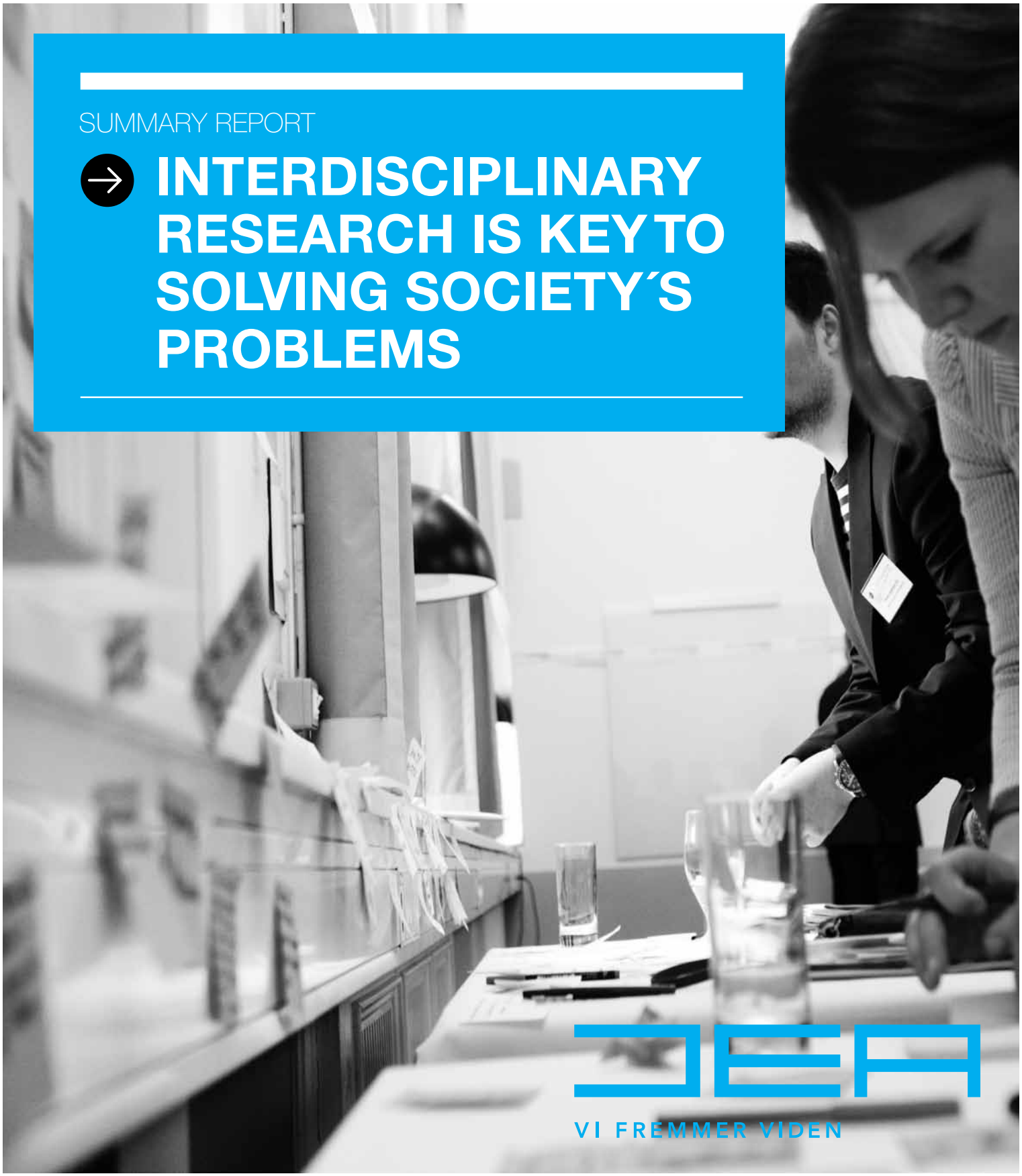
SUMMARY REPORT

INTERDISCIPLINARY RESEARCH IS KEY TO SOLVING SOCIETY´S PROBLEMS



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PREFACE

All over Europe there is a wish to promote research and innovation that can help address major societal concerns, or "grand challenges" as called in the EU Framework Programme for Research and Innovation, Horizon 2020. The communication from the European Commission on Horizon 2020 stresses that those challenges require that we bring together resources and knowledge from different fields, technologies and scientific disciplines. We need to be better at getting the so-called "hard" sciences – the natural and technical sciences – and the so-called "soft sciences" – the social sciences and the humanities (or SSH, for short) – to work together.

The reason is fairly simple: good solutions to important problems – whether that is in industry or larger societal problems – are rarely found within a single discipline; instead, solving complex, real-life problems generally requires bringing together insights from multiple disciplines. Thus, one of the success criterions for Horizon 2020 is to promote and effectively support interdisciplinary research.

But what is interdisciplinary research? Even though the societal importance of interdisciplinary research is widely recognized, there is relatively little knowledge about the nature of interdisciplinary research. We need to be able to answer questions such as: how much research is carried out as interdisciplinary research? And if you engage in interdisciplinary research does that require something else than monodisicplinary research? What are the barriers? And what incentives do we need, if we want to proceed in this direction? We need knowledge so we can identify the measures that will support research that tackles these grand societal challenges.

Therefore, DEA has carried out a study of interdisciplinary research. By case illustration we have looked at the correlation between interdisciplinary research and productivity, impact and cooperation and we have produced new knowledge to identify barriers and possibilities for interdisciplinary research. The study shows that while Danish research overall has high productivity and impact in all three case illustrations there is a potential for greater interdisciplinarity in the three chosen fields.

The main conclusions in this study is evidence of a positive and significant relationship between interdisciplinarity and impact. In order words, the more interdisciplinary a publication is, the higher the level of impact it is likely to have. Thus, at least in the three research fields examined, interdisciplinary publications appear to be rewarded, and not penalized, in terms of scientific performance.

Enjoy the reading!

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AIMS OF THE STUDY

The aim of the study is to stimulate the debate on how Horizon 2020 and other large research programs should be designed with a view to encouraging and supporting interdisciplinary research collaboration.

We therefore explore the usefulness of a new method for measuring the interdisciplinarity of research, see more on page 25. The method, which was developed in academia and uses bibliometric data (that is, data on scientific publications), is applied in case studies of three selected research fields: **genetically modified foods**, **meta-bolism and obesity**, and **renewable energy**.

The study will:

- Call for more evidence-based use of public funds to promote interdisciplinary research.
- Provide more general insights into the challenges associated with promoting greater interdisciplinarity in research.
- Explore the usefulness of a new bibliometric method for assessing the interdisciplinarity of research.

Multidisciplinarity vs. interdisciplinarity

Interdisciplinary research is necessary to address problems whose solutions cannot be identified within a single discipline. However, while research projects often involve scientists from multiple disciplines, this does not necessarily mean that the research in the project is truly interdisciplinary. There is an important distinction between multidisciplinarity and interdisciplinarity.

In interdisciplinary research, insights and methods from different scientific disciplines are integrated and used to investigate a jointly defined research problem through a joint research effort. By contrast, in multidisciplinary research, related research problems are investigated from different disciplines. The extent to which researchers from the different disciplines communicate with and draw inspiration from each other may differ, but there is no real integration of insights and methods from the participating disciplines.

Another important difference between multidisciplinary and interdisciplinary research is their effect on the research fields they bring together. According to a report from the National Academies (2005), in multidisciplinary collaboration, researchers from different disciplines work on a common problem and split apart unchanged once their task has been accomplished. Interdisciplinary collaboration, however, has the potential to forge new research fields or disciplines.

MAIN CONCLUSION 1: DANISH RESEARCH HAS HIGH OVERALL PRODUCTIVITY AND IMPACT

The three case studies indicate that Danish research in all three fields has **high productivity** relative to the size of the population. Denmark is the most productive country worldwide, measured on the number of scientific publications per capita, in all three case study areas. In other words, considering the size of the country, Denmark makes a substantial *contribution* to international research.

The case studies also reveal that Danish research has **high scientific impact**, meaning that it makes a significant *difference* on the international research front.

The level of impact varies, however, across research fields. For example, Danish research has a significantly higher impact in metabolism and obesity research and research on renewable energy than in research on genetically modified foods.

SCIENTIFIC IMPACT OF DANISH RESEARCH

Genetically modified foods: Denmark is ranked no. 18 out of 20 OECD countries

No. 1: USA (47.8 citations per publication)
No. 2: Italy (37.5 citations)
No. 3: England (36.2 citations)
No. 4: Germany (32.6 citations)
No. 5: The Netherlands (30.5 citations)
...
No. 18: Denmark (14.7 citations)

Metabolism and obesity: Denmark is ranked no. 4 out of 20 OECD countries

No. 1: Finland (37.5 citations per publication)
No. 2: USA (28.5 citations)
No. 3: Sweden (28.0 citations)
No. 4: Denmark (25.7 citations)
No. 5: England (24.9 citations)

Renewable energy: Denmark is ranked no. 2 out of 20 OECD countries

No. 1: USA (19.4 citations per publication)
No. 2: Denmark (18.1 citations)
No. 3: The Netherlands (17.2 citations)
No. 4: Switzerland (17.1 citations)
No. 5: Germany (15.8 citations)

Based on publication data from Thomson Reuters Web of Science 2000-2011 (both years included).

MAIN CONCLUSION 2: THERE IS A POTENTIAL FOR GREATER INTERDISCIPLINARITY IN DANISH RESEARCH

The level of interdisciplinarity in all three research fields is on par with or below the international level for all fields. This, combined with the results of our case studies, suggests that there is a potential to increase the level of interdisciplinarity in Danish research.

Among our three research fields, this is especially the case for research on genetically modified foods and on renewable energy.

The case studies indicate that discipline spanning research in the three research fields is predominantly multidisciplinary rather than interdisciplinary. The potential for greater cross-cutting research therefore lies in strengthening the degree of interaction among scientific disciplines.

DANISH INTERDISCIPLINARITY SCORE[1]

Genetically modified foods: Denmark is ranked no. 20 out of 20 OECD countries (score: 0,12)

No. 1: South Korea (0,19)
No. 2: Japan (0,18)
No. 3: France (0,18)
No. 4: Italy (0,17)
No. 5: Spain (0,17)

Metabolism and obesity: Denmark is ranked no. 8 out of 20 OECD countries (score: 0,12)

No. 1: Japan (0,13)
No. 2: Switzerland (0,13)
No. 3: Finland (0,13)
No. 4: England (0,13)
No. 5: USA (0,13)

Renewable energy: Denmark is ranked no. 14 out of 20 OECD countries (score: 0,16)

No. 1: South Korea (0,18)
No. 2: Taiwan (0,17)
No. 3: China (0,17)
No. 4: Italy (0,17)
No. 5: France (0,17)

Based on publication data from Thomson Reuters Web of Science 2000-2011 (both years included).

[1] *The method in its current version tends to yield interdisciplinarity scores that are both quite low and lie within a relatively small range. This limitation is recognized in the academic literature, and efforts are underway to remedy it, for example by performing separate analyses on the three dimensions (variation, balance and distance) that are used in the calculation of the interdisciplinarity index. Nonetheless, we still find the method useful in drawing out differences in degrees of interdisciplinarity that can provide the starting point for more in-depth research.*

BARRIERS TO INTERDISCIPLINARITY

The case studies indicated that Denmark has good overall conditions for interdisciplinary research. Several Danish research funders provide grants for large, interdisciplinary research projects. For instance the Council for Strategic Research explicitly wishes to promote interdisciplinarity, while the Danish National Advanced Technology Foundation promotes problem-oriented research collaboration between universities and industry.

The explanation for why researchers chose not to engage in interdisciplinary research must therefore be found elsewhere. The case studies suggest several reasons for why researchers choose mono- or multi-disciplinary research over interdisciplinary ventures:

Interdisciplinary research is uncertain and resourcedemanding

Engaging in integrative research involving several disciplines requires participants to first establish a common "language" and research method that enables them to work jointly while exploiting the potential from cross-fertilization between their disciplines. This process can be very demanding in terms of the time and energy that researchers must invest in it. Moreover, its outcomes are highly uncertain, as interdisciplinary projects often break new ground and are therefore associated with a high level of risk. This may lead researchers to opt for more accessible research projects with a higher likelihood of success.

Interdisciplinary research can be more difficult to publish in prestigious journals

The case studies also lend support to an often mentioned barrier to interdisciplinarity, namely that the results of interdisciplinary research are more difficult to publish in prestigious academic journals because these journals are generally focused on specific disciplines. They may also lack the necessary breadth of disciplines among their external reviewers to satisfactorily assess the quality of interdisciplinary submissions. Multidisciplinary journals like *Nature* and *Science* are therefore exceptions to the rule. Respondents, however, also indicate that the ability to publish interdisciplinary work in high-impact journals differs greatly across research fields and is not always an impediment to interdisciplinarity.

The value of interdisciplinarity is unclear

According to respondents, many researchers do not see the value of interdisciplinarity over multidisciplinary research and therefore lack incentive to overcome the barriers associated with interdisciplinary research projects.

Research problems are defined within disciplines rather than based on societal challenges

The case studies also suggest that the reason many researchers do not see the value of interdisciplinarity may be that they are content to address research issues within their own disciplines. In contrast, researchers that take an interest in broader societal problems appear more open to interdisciplinary approaches.

Disciplines often operate with a basic set of assumptions and research methods that affect their research focus

Moreover, disciplines are prone to "fads", i.e. popular topics that influence the current research agenda. Research problems that are defined within a particularly disciplinary context therefore often have a very different nature than applied research problems that are based on societal challenges. The latter tend to be much more complex and require inputs from several different disciplines.

MAIN CONCLUSION 3: THERE IS SUBSTANTIAL COLLABORATION BETWEEN THE HARD AND SOFT SCIENCES – BUT MUCH OF IT IS MULTIDISCIPLINARY RATHER THAN INTERDISCIPLINARY

As indicated by table 1, just three percent of all Danish publications identified from the three research areas are SSH publications, defined as publications with one or more authors from SSH university departments and faculties.[2] A large proportion of these publications, however, are co-authored with researchers from technical and/or natural science departments and faculties. For research on genetically modified foods and renewable energy, approximately one third of all SSH publications are co-authored with the hard sciences, while this is true for almost all SSH publications in metabolism and obesity research. These results should be taken with a grain of salt, as they are based on an analysis of just 39 publications. Nonetheless, they indicate that there is substantial interaction between the hard and soft sciences in the three research areas examined.

TABLE 1: SSH publications in each of the three case study research areas

Source: DAMVAD, 2012

	Total no. of Danish publications in the field	No. of these publications that are SSH publications (pct. of all Danish articles)	No. of these SSH publications that are co-authored with the hard sciences (pct. of all SSH articles)
Genetically modified foods	186	19 (10 pct.)	7 (37 pct.)
Metabolism and obesity	738	9 (1 pct.)	8 (89 pct.)
Renewable energy	312	11 (4 pct.)	3 (27 pct.)
Total	**1,236**	**39 (3 pct.)**	**18 (46 pct.)**

[2] *The relatively low proportion of SSH research may be partly explained by the fact that SSH researchers publish fewer scientific articles than their counterparts in the natural and technical sciences. The results may also be affected by the fact that data was collected from Thomson Reuters Web of Science. This database has generally been preferred in studies that span a broad range of disciplines and sciences, while Elsevier's Scopus – the other leading bibliometric database – has had better coverage of the SSH. As explained earlier, these differences have been reduced in recent years, as both databases have made efforts to overcome their shortcomings. Nonetheless, it should be noted that SSH research may be underestimated in our study.*

EXAMPLES OF SSH RESEARCH FROM THE THREE CASES

Genetically modified foods:

- Bioethics (e.g. examined from a philosophical or business perspective)
- Food economics; health economics
- Customer relations in the food sector
- Environmental impact

Metabolism and obesity:

- Philosophy
- Economics and psychology
- Firms' efforts to increase employee health

Renewable energy:

- Economics and management
- Environmental studies
- Environmental regulation in municipalities

Based on publication data from Thomson Reuters Web of Science 2000-2011 (both years included).

However, the qualitative case studies also indicate that this interaction is often multidisciplinary rather interdisciplinary, and that the degree of interdisciplinary collaboration falls the further apart two disciplines are. The case studies suggest a number of factors that may explain why researchers find it challenging to bridge SSH research with research on the natural and technical sciences.

BARRIERS TO INTERDISCIPLINARY COLLABORATION BETWEEN THE HARD AND SOFT SCIENCES

Lack of contact to potential collaborators

Universities and academic research communities are largely organised based on traditional academic disciplines. This creates limited opportunities to meet researchers from other communities. As a result, researchers also lack insight into research topics in other fields which makes it more difficult to identify promising areas for interdisciplinary research.

Few obvious points of collaboration

When researchers from different disciplines share research interests, they often focus on very different aspects of these interest areas. This makes it more challenging to identify research problems of common interest. In some research areas this is far easier; for example, study of the development of the market for electric cars requires both technical insight into the production of cars and the development of the necessary infrastructure and economic insight into the costs of acquiring and maintaining an electric vehicle. When joint research interests are harder to come by, the likelihood of entering into collaboration decreases.

Lack of incentive to collaborate

Many of the barriers related to interdisciplinary research collaboration increase with the distance between disciplines, including for example the development of a common language and research methodology. Moreover, interdisciplinary research can be difficult to publish in high-impact journals. Several respondents also pointed out that interdisciplinary research requires participants to choose a clear publication strategy early on (including which journals to target) to increase the chances that publications will be suitable for and accepted by good journals. Overcoming barriers like this requires a significant investment of time and resources on the part of researchers, which occurs at the detriment of other activities, e.g. pursuing more accessible research and publications within the researchers' own fields.

Cultural barriers

According to respondents, many researchers do not see the value of interdisciplinary collaboration. Particularly in some areas of SSH research, interdisciplinary research is perceived as less prestigious, and the demand for applied, problem-oriented research is lower than in many hard sciences.

Social science and humanities research often becomes an "appendix"

When social science and humanities are incorporated into multidisciplinary research projects, they are often brought in as an "add on", or as an independent project within the main project. This is in large part due to the difficult, time-consuming and uncertain nature of integrative research. Moreover, SSH researchers are often not closely involved in the preliminary formulation of the research problem that defines the joint project.

Necessity is the mother of invention

Finally, the case studies and interviews also indicated that because of the aforementioned barriers to interdisciplinary collaboration between the hard and soft sciences, such collaboration often occurs because researchers have no other viable options to pursue. For instance, one respondent from the humanities explains that very little public or private funding is available in his field of research. He therefore approaches potential collaborators from the natural and technical sciences because of their access to funding. On a similar note, researchers working with animal models in clinical research are often open to working with ethics researchers because of public concerns regarding animal welfare.

AN EXAMPLE OF INTERDISCIPLINARY COLLABORATION THAT SPANS THE HARD AND SOFT SCIENCES

The Danish Centre for Bioethics and Risk Assessment (CeBRA) is committed to performing interdisciplinary research, where ethical issues are studied in connection with biological research within food production, biotechnology and animal sciences. The centre is organized as a partnership between parts of the University of Copenhagen, Aarhus University, and the Technical University of Denmark. Research undertaken is performed at the host universities, based on external grants, but CeBRA facilitates an interdisciplinary approach across universities and disciplines. The research performed at CeBRA makes a substantial input to both the scientific study of and the public debate on bioethics.

The director of the centre, Professor Peter Sandøe, is a strong advocate for interdisciplinary work and is one of the main drivers behind the interdisciplinary research center. In relation to his work, Sandøe stresses that we must understand technical issues in the context of our society in order to understand exactly what challenges we are facing and how these can be solved.

This calls for interdisciplinary work, where the humanities and social sciences can link the work of the natural and technical sciences. Biological discoveries and inventions involve both opportunities and risks for society; and a wide perspective is therefore needed in to conceptualize these opportunities and risks.

According to Sandøe, scientists should involve themselves in the public debate as informed citizens, but often stay out of it precisely because they are scientists and – for some – because they fear criticism or interference in their work.

The public debate on genetically modified foods in the 1990s is, according to Sandøe, an example of a situation where a lack of public dialogue from the start led to a development with a more or less wholesale rejection of these foods.

A key purpose of CeBRA is to address such shortcomings and thus allow the public and policymakers to make more informed decisions about new biotechnological innovations.

MAIN CONCLUSION 4:
INDUSTRY PRODUCES BOTH HIGH IMPACT AND HIGHLY INTERDISCIPLINARY RESEARCH – BUT NOT AT THE SAME TIME

Eight percent of all the Danish publications identified from the three research areas were firm publications, defined as publications with one or more authors from private Danish companies.

As indicated by table 2, these company publications have – on average – both higher impact and a higher degree of interdisciplinarity than the total set of publications. It is not surprising that firms engage in interdisciplinary research, as they need to gather and synthesize inputs and methods from all relevant scientific disciplines in order to develop new products and solve concrete, practical problems. Industry research has, however, traditionally been associated with lower levels of scientific impact, as firms tend to do research on more applied issues, which generally receive fewer citations (and therefore has lower impact) than basic research. Contrary to expectations, the firms in all three of the research fields have produced high impact research. A more detailed examination of the publication suggests that firms produce high impact research when they collaborate with leading national or international research environments.

However, further analysis of the data shows that there is no significant correlation between publications where firm publications have a high scientific impact and those where they have high degrees of interdisciplinarity: in other words, they either publish high impact research or interdisciplinary research.

Closer inspection of the bibliometric data also reveals that applied research institutions (e.g. government research institutions), like private firms, exhibit a high degree of interdisciplinarity, although they generally speaking have relatively few publications and low scientific impact.

Moreover, we find that while the level of scientific impact differs greatly for research from the various Danish universities, the universities have lower overall levels of interdisciplinarity. This is not surprising, as universities have a responsibility to maintain and develop strong disciplinary research and are, to a large extent, organized into research units based on scientific disciplines rather than societal challenges.

In addition, a key rationale for the public funding of universities is that these institutions are both able to and responsible for ensuring the long-term development of specialized knowledge and research methods within given disciplines that interdisciplinary research can build on.

Our findings also suggest, that part of the explanation for the lower relative level of interdisciplinarity in

TABLE 2: Firm publications vs. publications in each of the three case study research areas

Source: DAMVAD, 2012

	Total no. of Danish publications in the field	Average no. of citations per publication	Average interdisciplinarity score
Genetically modified foods			
Firm publications only	18	11.90	0.15
All Danish publications	186	10.45	0.14
Metabolism and obesity			
Firm publications only	32	28.90	0.13
All Danish publications	738	23.00	0.12
Renewable energy			
Firm publications only	46	18.39	0.16
All Danish publications	312	12.28	0.14
Total			
Firm publications only	96	19.75	0.15
All Danish publications	1,236	15.24	0.13

universities' research lies in aforementioned barriers to interdisciplinarity, e.g. that interdisciplinary research is uncertain, resource-demanding and can be difficult to publish in prestigious academic journals. This indicates that there is potential to stimulate greater interdisciplinarity in Danish universities, at least within the three research fields examined in the case studies, if these barriers are mitigated.

However, the case studies indicate that firms that engage in collaboration with universities are often not involved early on in the design of interdisciplinary research projects, but included after the main research problem has been formulated. This implies that their inputs are not fully exploited. In the worst cases, this can mean that companies become symbolic or peripheral participants in the projects, much like social science and humanities research risks becoming an appendix in projects defined primarily from the vantage point of the natural or technical sciences.

Our findings suggest that greater collaboration between universities and applied research institutions and/or companies may also stimulate more problem-oriented research and thereby potentially more interdisciplinary collaboration. The qualitative studies indicate, however, that this requires that the collaborative research is problem-oriented in nature and that applied research institutions and firms are involved from the very beginning of the project, including especially in the initial definition phase of the research problem, to ensure that their particular insights are brought to bear on the foundation for the joint research project.

MAIN CONCLUSION 5: INTERDISCIPLINARITY IS GOOD FOR IMPACT, BUT ONLY WITHIN THE HARD SCIENCES

Part of the study included a multivariate regression analysis that allowed us to analyze the relationship between interdisciplinarity and other key aspects of academic research, notably scientific impact and collaboration with industry. This is based on the idea that if there is a significant relationship between interdisciplinarity and key aspects of scientific performance, this is likely to affect academic researchers' incentives to engage in interdisciplinary research and must therefore be taken into account in the design of public policy to promote interdisciplinarity.

KEY FINDINGS OF THE REGRESSION ANALYSIS

- A positive and significant relationship between interdisciplinarity and impact.
- Having one or more authors from the social sciences and humanities on a publication was associated with a lower impact.
- Having one or more authors from private industry did not have any effect on the scientific impact of an article.
- For interdisciplinary publications, having a co-author from the SSH or from industry was associated with lower scientific impact.

In general, we find evidence of a positive and significant relationship between interdisciplinarity and impact. In other words, the more interdisciplinary a publication is, the higher the level of impact it is likely to have. Thus, at least in the three research fields examined, interdisciplinary publications appear to be rewarded, and not penalized, in terms of their scientific performance.

Moreover, having one or more authors from the social sciences and humanities was associated with a lower impact. This is likely to be explained by the fact that the soft sciences generally receive fewer citations than the hard sciences. It does, however, have implications for the researchers seeking to publish results from collaboration between the hard and soft science: if they publish in social science and humanities journals. This is likely to have a negative effect on the scientific impact of any natural or technical scientists that collaborate with them.

In contrast, having one or more authors from private industry did not have any significant effect on the scientific impact of an article.

Publications that have both a high interdisciplinarity score and at least one author from the social sciences and humanities or from industry are associated with lower levels of scientific impact.

These findings indicate that there are substantial disincentives for university researchers to engage in interdisciplinary research collaboration with SSH or firm researchers or, in other words, precisely the type of interdisciplinarity that is aimed for in Horizon 2020.

KEY FINDINGS FROM THE CASE STUDIES

RESEARCH ON GENETICALLY MODIFIED FOODS

Denmark is the most productive country worldwide, measured on the number of scientific publications per capita, in the field of research on genetically modified (GM) foods. Denmark lags behind many of the 20 leading OECD countries in the field, however, when measured on the levels of interdisciplinarity and scientific impact, where Denmark is ranked, respectively, at number 20 and 18.

Interdisciplinary research primarily occurs among closely related disciplines

The bibliometric analysis shows that interdisciplinary research primarily occurs within the natural and technical sciences. A small subset of research in the field is, however, based on collaboration between the natural and technical sciences on the one hand and social sciences and humanities on the other; this research primarily concerns ethical issues related to GM foods. In fact, ethics are such a significant topic in research on GM foods that interdisciplinary research groups and committees have been established, including for example the aforementioned Centre for Bioethics and Risk Assessment (CeBRA).

On a related note, the Nordic Committee on Bioethics promotes Nordic cooperation and exchange between relevant parties within bioethics. The Committee is funded by the Nordic Council of Ministers and organizes events and publishes publications within bioethics.

Across the various disciplines in the field, there is consensus that research on GM foods requires simultaneous breadth and depth. “Breadth” refers to the importance of engaging in boundary-crossing research that integrates relevant elements from various disciplines. Meanwhile, “depth” refers to the need for strong monodisciplinary knowledge and research methods. In other words, respondents argue that good interdisciplinary research comes from researchers with a solid grounding in their respective disciplines.

There is funding for interdisciplinary research – but reviewer panels should be interdisciplinary

Adequate funding appears to be available for interdisciplinary research in GM foods, both in Denmark and in the EU. However, it is stressed that the panels that review interdisciplinary research applications should themselves have an interdisciplinary background that enables them to fully assess the potential value and quality of interdisciplinary applications.

Academic barriers to interdisciplinarity

Within GM foods, it can be difficult to get interdisciplinary work published in more prestigious journals, as these are often focused on a particular discipline.

Moreover, some respondents from the field have experienced that interdisciplinary work is not as highly recognized by peers as monodisciplinary research. Such barriers can lead researchers to choose monodisciplinary research projects over interdisciplinary ones.

Companies promote problemoriented, interdisciplinary research

The bibliometric analysis indicated that scientific publications, which were authored or co-authored by researchers from industry generally have significant scientific impact. Moreover, industry publications also had a higher overall level of interdisciplinarity, compared to all Danish publications in the field.

The case study indicates that this may be because companies engage in research of a more problem-oriented, applied character: they take as their point of departure not a given discipline but a specific problem that needs to be solved.

For example, a respondent from the company Chr. Hansen explained that due to the highly critical public debate on GM foods in the late 1990s, they chose to rethink their research efforts to provide the basis for a more informed (and open) public opinion towards GM foods. In its own words, the company therefore performs research not for product development, but for knowledge development.

Also, the organization of companies can have a significant impact on their ability to undertake interdisciplinary research, as they are most often organized according to business areas. This may foster more work across disciplines than at traditional research institutions, which are organized according to disciplines. Moreover, firms do not have to stay as "true" to the methods and assumptions of a given discipline as academic researchers often must in order to get published in prestigious journals.

Most of the research conducted in the industry is undertaken in collaboration with scientists from universities or other public research institutions. Thus, there seems to be a strong relationship between companies and public research institutions within research on GM foods, and public scientists also reported that companies play an important role in the GM foods research community.

Companies in the GM food industry contribute to scientific publications and conferences for several reasons. This interaction provides firms with a platform for engaging with the research community and thus for potential collaboration. Interestingly, the companies also publish their papers as a way to perform quality control of their research, based on the citations and responses that they receive within the research community.

RESEARCH ON METABOLISM AND OBESITY

Overall, metabolism and obesity are areas in which Danish research is doing very well. Denmark is the first most productive country measured on the number of scientific publications, corrected for the number of inhabitants. In addition, Danish research has the fourth highest impact of the leading 20 OECD countries in this field of research.

Furthermore, Danish research on metabolism and obesity comes in as number eight when ranked on its level of interdisciplinarity; however, all the 20 OECD countries score very similar levels of interdisciplinarity (ranging from 0.12 to just 0.13 on a scale from 0 to 1).

Long tradition of combining disciplines when aiming to address obesity-related challenges

Research within metabolism and obesity has a long tradition of combining technologies and disciplines. The very nature of the research field motivates an interdisciplinary approach, as it has become evident that, in order to fight obesity, a change in human behavior and wellbeing is as important as getting the right kind of medical advice and treatment.

The recognition that multiple disciplines are required to fight obesity is hence a common and widespread perception within the research field, and has been so for several years. Thus, it is emphasized that a significant amount of collaboration occurs across the hard and soft sciences. However, collaboration among closely related disciplines is still most common.

Industry and hospitals play an important role

The bibliometric analysis has revealed that companies have both a high degree of interdisciplinarity and a high impact in their publications. The role of companies in research differs, ranging from providing inputs to academic research to actively contributing to driving the research forward.

A "Novo Nordisk effect" is apparent in this case study. The company participates in almost half of all publications in the field that are co-authored by Danish firms. Novo Nordisk participates in a substantial amount of research with a broader perspective than merely the development and testing of new drugs. Novo Nordisk also supports basic (mostly interdisciplinary) research related to obesity and diabetes. This has helped build strong links to universities and other research institutions, and thus stimulated the participation of Novo Nordisk in various academic research projects within obesity.

Like industry, hospitals have a high degree of interdisciplinarity and high impact in their publications in this field. In their organizational structure, hospitals are predisposed to interdisciplinarity, as they are often organized around themes (such as obesity) and with multiple disciplines represented within each of those themes.

Interdisciplinarity and academic prestige

Overall, academics researchers experience that interdisciplinary research creates better research, thus enhancing their ability to publish in the prestigious journals. It is stressed that medical journals are often concentrated on a topic (such as obesity or diabetes), which makes it easier to combine different methods and disciplines.

Moreover, the importance of such combination seems to be increasing. A substantial number of key journals are enthusiastic about interdisciplinary research that cuts through "old perceptions", as put by one respondent. However, interdisciplinary research places great demand on dissemination as methods and results

must be communicated beyond the individual discipline and without the presumption of prior knowledge among the audience.

Different disciplinary traditions tend, however, to constitute barriers to publication of interdisciplinary research results. As it is not always possible or desirable to target interdisciplinary journals, scientists have to choose which journals to publish in, early on in the research process, so that they may target their research and make it more palatable for the chosen journal. In addition to this, there are different traditions for crediting authors across the disciplines, which may also pose a minor challenge to the publication of interdisciplinary research.

Interdisciplinary obesity platforms are catalysts for interdisciplinary research

Within research on metabolism and obesity, it is evident that strong research platforms play an important role as an enabler of research across disciplines. Examples of such platforms include The Novo Nordisk Foundation Center for Basic Metabolic Research based at the University of Copenhagen, a Nordic Center of Excellence Program on Food, Nutrition and Health financed by Nordforsk, and the OPUS Center based at the University of Copenhagen with financial support from the Nordea Foundation.

These platforms provide an opportunity for scientists, hospitals and industry to meet around a common theme, but across disciplines. This serves as a point of departure for future projects on metabolism and obesity research that combine different perspectives and disciplines in order to solve a common problem.

RESEARCH ON RENEWABLE ENERGY

Denmark holds a strong position within research on renewable energy, measured both on the number of scientific publications per capita and scientific impact, where Denmark ranks first and second, respectively, among the 20 leading OECD countries in the research field. Denmark ranks somewhat lower on the degree of interdisciplinarity, namely at number 14.

The high productivity and impact of Danish renewable energy research is the combined result of many years of scientific research, a persistent political focus on renewable energy, and companies' continuous research and development efforts.

Interdisciplinarity plays a key role – but mainly among closely related disciplines

The bibliometric analysis has indicated a relatively low degree of interdisciplinarity in research within renewable energy. However, interdisciplinarity is seen as a prerequisite for energy research and hence practiced among scientists. This is based on the perception that nature and society are not organized according to disciplines, and a combination of technologies is therefore needed to get the right understanding and provide new perspectives and solutions for the renewable use of energy. An example of this is research on how electric cars can be used as storage for excess energy in a way which is both economically sound and in tune with consumers' needs and preferences.

Solving energy problems requires combining different disciplines, though energy research mostly combines closely related disciplines, particularly within the technical sciences. However, the study has also identified examples of research projects that involve the soft sciences, notably economics.

Understanding the interplay between the technological developments within renewable energy and viable business models, for instance in relation to electric cars and solar cells, is becoming increasingly important and calls for an interdisciplinary approach.

Interdisciplinarity and academic prestige

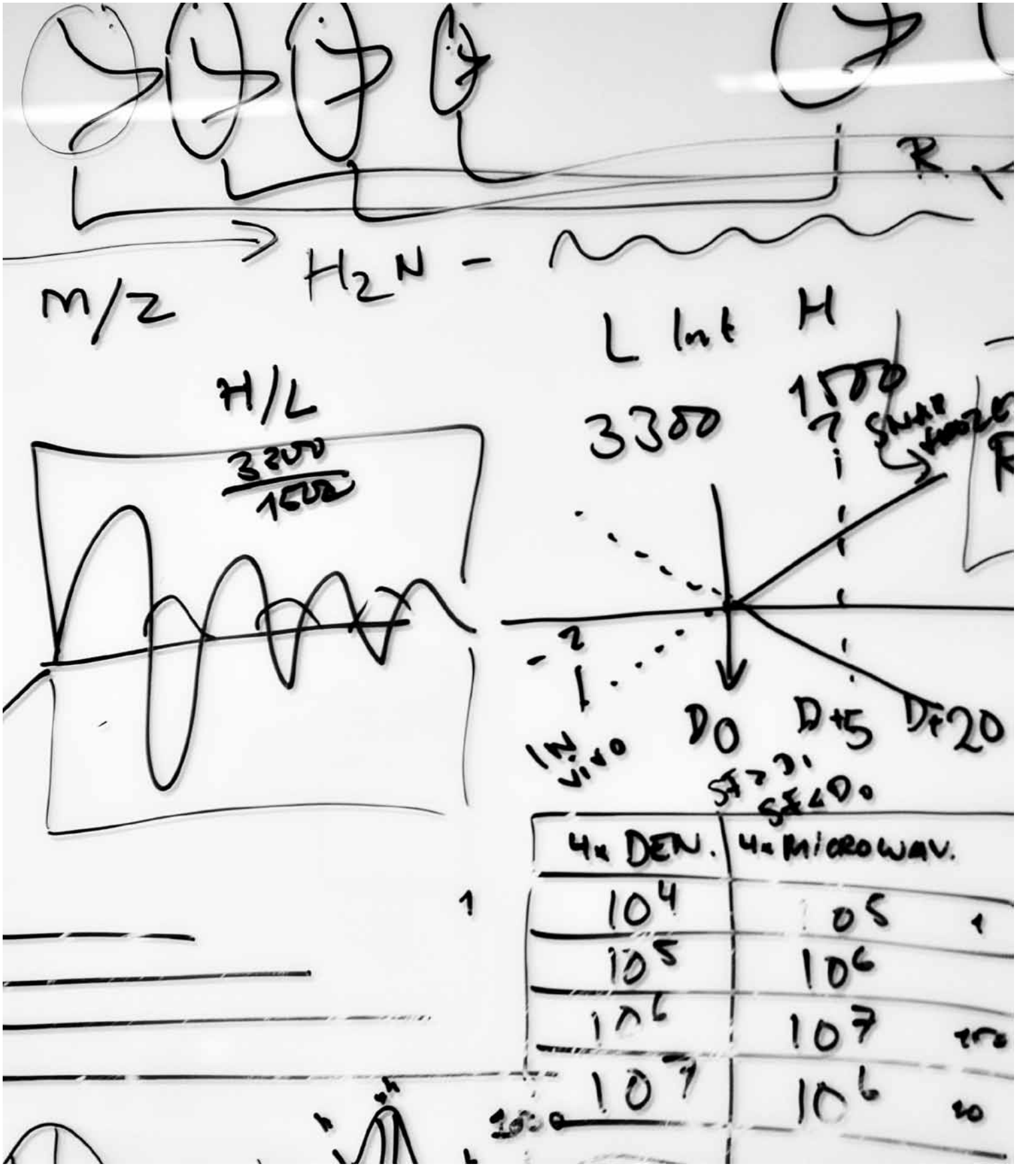
A closer look at the bibliometric analysis reveals that the publications that have the highest degree of interdisciplinarity do not have the highest impact. Insights from the study has indicated that interdisciplinary energy research can have difficulties getting accepted in established journals, which often have a more monodisciplinary focus. Thus, interdisciplinary articles often get published in newer journals that tend to have a more outspoken focus on interdisciplinary research but also lower scientific impact.

The role of industry research

The bibliometric analysis also showed that a substantial number of companies contribute to research on renewable energy. The study revealed that energy research tends to be more applied than basic in nature, which may explain why industry research plays a significant role.

The bibliometric analysis also revealed that industry research generally has a high degree of interdisciplinarity compared to university research; which may be explained by the fact that companies are driven by a need to solve specific problems, which forces them to combine inputs from a variety of sources and disciplines.

Interviews also suggest that much private energy research is undertaken in collaboration with public research institutions, and that these collaborations also tend to be problem-oriented and therefore interdisciplinary. The collaborations are moreover driven by strong ties between industry and university researchers that result partly from the fact that industry researchers often maintain an affiliation with the university where they did their research training.



4x DEN.	4x MICROWAV.
10^4	10^5
10^5	10^6
10^6	10^7
10^7	10^6

RECOMMENDATIONS

In conclusion, interdisciplinary research does not occur to the extent that society would like it to occur, because a number of barriers make it less attractive for academic researchers and companies to engage in.

First, both the process and the outcomes of interdisciplinary research are highly uncertain, because interdisciplinarity involves venturing into unchartered territory. This makes it less attractive both to firms that seek a financial return on their investments in research, and to academic researchers, whose scarce time and resources must be spent efficiently, for instance generating scientific publications.

Second, interdisciplinary research requires the development of a common "language" and common research methods that allow the participants to engage in joint research. It also requires representatives of all participating disciplines to be involved in the initial definition of the research problem and design of the research project. Such collaboration is both time-consuming and demanding.

Third, it can be difficult to find collaborators, as researchers typically have strong professional ties within their own disciplines, but not to other disciplines. Thus, researchers often lack both insight and networks into other research fields, which makes it difficult to identify and establish interdisciplinary collaboration.

However, our findings that interdisciplinary publications are likely to have higher scientific impact also suggest that there are strong incentives toward interdisciplinarity that can help outweigh the uncertainty and costs associated with boundary-spanning research.

Nonetheless, because of these aforementioned barriers, public policies that encourage and support interdisciplinary research are necessary to ensure that a societally desirable level of interdisciplinary research occurs. This is especially true for interdisciplinary research that spans the hard and soft sciences.

It is important to stress, however, that interdisciplinarity is a mean to an end, and not an end itself. Policies to stimulate interdisciplinary research must therefore be designed to mitigate barriers to interdisciplinarity where greater interdisciplinary research collaboration can help address major societal challenges without having negative unintended effects on the direction or quality of academic research.

Public programs that encourage interdisciplinary research that does not add value or that do not take barriers to interdisciplinary research into consideration are likely to lead to "symbolic" interdisciplinarity alone, i.e. projects which are interdisciplinary on paper but not in practice.

In addition, our case studies indicate that there is a division of labor in interdisciplinary research among various actors in the research system, notably among universities and firms but also hospitals and applied research institutions. The universities are more monodisciplinary in their nature because they have a responsibility for ensuring development of specialized knowledge. The companies, hospitals and applied research institutions are more interdisciplinary because the research produced there are more problem-oriented. To effectively promote interdisciplinary research, public policy must consider and support this division of labor – or seek to alter it, in those cases, where the lack of interdisciplinarity is due to a lack of resources, willingness or incentives to engage in it.

For example, our study suggests that collaboration with industry can promote greater problem-orientation in academic research, provided that firms are brought to bear on the definition of joint research problems, goals and methods at the start of the collaboration.

Moreover, good interdisciplinary research builds on strong disciplinary foundations. Thus, interdisciplinary research is an important supplement (and not an alternative) to research, which is anchored in specific scientific disciplines.

In view of the substantial barriers to interdisciplinary research relative to multidisciplinary research – and the penalties that it may involve for particularly university scientists – it is also important to make a careful assessment of the circumstances under which interdisciplinarity will contribute significant value added for society, for example as compared to multidisciplinary research.

Finally, the case studies pointed to a number of key barriers to interdisciplinary research. They also suggested a number of possible means of overcoming these barriers; the most important of these potential remedies are described on page 24.

REFLECTIONS ON THE METHODOLOGY

The bibliometric method for measuring interdisciplinarity that was investigated in this study is interesting, because it presents an opportunity to explore the degree of interdisciplinarity in research within different fields and between different sets of actors in the research community. It is however presented as possible supplement to, and not a substitute for, other means of assessing multi- or interdisciplinarity in research.

Some limitations of the approach should be noted. First, the method only captures interdisciplinary collaboration, which results in publications. However, researchers rarely engage in research that does not generate publications.

Second, the method in its current version tends to yield interdisciplinarity scores that are both quite low and lie within a relatively small range. This limitation is recognized in the academic literature, and efforts are underway to remedy it, for example by performing separate analyses on the three dimensions (variation, balance and distance) that are used in the calculation of the interdisciplinarity index. Nonetheless, we still find the method useful in drawing out differences in degrees of interdisciplinarity that can provide the starting point for more in-depth research.

Finally, it should be noted that the research fields were defined based on existing insight into the three choosen study research areas and recent review of research within these fields, and not by a panel of experts. Thus, our data collection may have underestimated the total number of Danish publications in the three fields in our effort to limit “noise” from other reseach fields captured in the search.

TABLE 3: Overview of key barriers to interdisciplinarity and suggestions for how to deal with them

Source: DAMVAD and DEA, 2012

BARRIERS TO INTERDISCIPLINARITY	POSSIBLE REMEDIES
Researchers underestimate the difficulties and the investment of time and resources involved in developing a "common language" and a joint set of research tools, which are necessary for interdisciplinary research.	Interdisciplinary research projects should be large and long enough to allow for the development of a "common ground". Part of the funding should be reserved for the pursuit of new research avenues or challenges that were not anticipated at the outset of the collaboration. Funding should include possibilities for research stays or other forms of co-location (either temporary or for the duration of the project). However, co-location should not be forced.
There is a high degree of uncertainty regarding the outcomes of interdisciplinary projects. This may lead researchers to pursue mono- or multidisciplinary projects that are less risky and over which the researchers have more control.	Provide funding for pilot projects, i.e. small projects that allow researchers to explore the usefulness of an interdisciplinary venture on a small scale before committing to larger, longer projects. This could for example be achieved on a test scale through student projects (e.g. Masters' theses).
Researchers tend to define research problems within their own disciplines and not in terms of broad societal challenges. This limits the need for interdisciplinary collaboration.	Encourage collaboration between discipline-oriented university researchers and problem-oriented researchers e.g. industry and/or applied research institutions. Define research centres that are focused on specific problems rather than traditional disciplines, and rethink the traditional faculty structure of the universities to respond to the call for excellence in interdisciplinary research. Post calls for solutions to societal challenges or prizes for the best interdisciplinary approaches to important societal challenges.
Many researchers lack personal networks to other disciplines and therefore have limited knowledge of potential collaborators and their research.	Promote networking across disciplines, e.g. by bringing a broad set of researchers together to discuss specific societal challenges. Such networking should however involve researchers that have a strong academic performance within their discipline, as good interdisciplinary research rests on strong disciplinary foundations.
Projects that start out with the intention of being interdisciplinary turn out to be multidisciplinary, in large part because the contributions of the various disciplines were not properly integrated at the start of the project.	Require interdisciplinary projects to involve all participants in joint identification of the research problem and the research approach from the outset. This is especially important for research that involves firms and for "hard science" projects that involve SSH researchers.

OUR APPROACH

DATA AND METHODS

We use data on scientific publications (socalled bibliometric data) to explore the actual degree of interdisciplinarity in research within three selected research fields. The objectives of the study were to:

1. **To collect all Danish publications published during the period 2000-2011 (both years included) in journals indexed in the bibliometric database Thomson Reuters Web of Science.**[3] Publications were considered to be Danish if they were written by at least one author affiliated with a Danish research institution or company.

2. **To analyse Danish publications in an international perspective.** The total set of Danish publications is compared to scientific publications from the 20 leading OECD countries in each field, on three dimensions:

    - **Productivity:** how many articles they published, i.e. how much they contributed to the international research front.

    - **Impact:** how often their articles had been cited, i.e. how great an overall impact they had made on the research front.

    - **Interdisciplinarity:** the level of interdisciplinarity of each of the articles, calculated as described more detailed on page 27.

3. **To analyse the degree and role of interdisciplinarity in the Danish research fields through further analysis of the bibliometric data combined with interviews with selected researchers from the public sector and from industry.** Respondents were identified in the bibliometric analysis and selected based on high levels of interdisciplinarity and/or impact, and approximately six interviews with researchers in Denmark and abroad were conducted in connection with each case study.

4. **To analyse the relationship between interdisciplinarity and other key aspects of academic research, notably scientific impact and collaboration with industry, using multivariate statistical analysis.** If there is a significant relationship between interdisciplinarity and key aspects of scientific performance, this is likely to affect academic researchers' incentives to engage in interdisciplinary research and must therefore be taken into account in the design of public policy to promote interdisciplinarity.

[3] *Publications were retrieved from Thomson Reuters Web of Science, one of the two major databases used for bibliometric studies, along with the Elsevier owned Scopus. Differences between the two databases are limited and mainly center on the number of journals covered, particularly in the social science and humanities. Several recent studies (e.g. Leydesdorff et al. 2010; Archambault et al. 2009) however conclude that the bibliometric indicators derived from the two databases differ only in extreme cases, e.g. research fields with very few publications.*

THE THREE CASE STUDY RESEARCH FIELDS

These research fields were selected because they all carry high relevance for the grand societal challenges that Horizon 2020 will focus on (see European Commission 2011 for more information). Moreover, all were expected (at least potentially) to have a substantial degree of interdisciplinary research, both within and across the hard and soft sciences.

Genetically modified foods: Genetically modified foods are based on plants or animals, where DNA has been modified through genetic engineering in order to enhance desirable characteristics e.g. to enable the greater, more effective production of crops. They are relevant for the Horizon 2020 challenge on *food security, sustainable agriculture, marine and maritime research and the bio-economy.*

Metabolism and obesity: Research on metabolism studies how the body metabolises food and how proper nutrition and exercise can contribute to healthy living. Obesity is a growing problem in many parts of the world and associated with a number of chronic conditions e.g. diabetes and cardiovascular diseases. This field of research is therefore important to address the Horizon 2020 challenge regarding *health, demographic change and wellbeing.*

Renewable energy: This research field aims to develop sustainable sources of energy (e.g. solar or wind energy) that can replace fossil fuel technology. Research on renewable energy will help to address the Horizon 2020 challenge to provide *secure, clean and efficient energy.*

THE INTERDISCIPLINARITY INDEX

During the last decade, academic researchers have developed a number of different methods for assessing the level of interdisciplinarity in research (for a review, see Leydesdorff and Rafols 2011). In recent years, academics have focused on one particular approach, which allows for the systematic assessment of the degree of interdisciplinarity in a body of research using an "interdisciplinarity index" (developed by Porter et al. 2007, Alkærsig 2011 and Rafols et al. 2012). The method is based on the analysis of publications in scientific journals, the main channel for the dissemination of scientific research and therefore also considered to be a reliable indicator of scientific activity.

We have adapted the method for the use in this study to include larger sets of publications, for instance all publications from a given country or research institution.

Essentially, the method determines the degree of interdisciplinarity of a particular publication (and thus of the research presented in that publication) based on the scientific disciplines that it cites.[4] Any scientific publication cites a number of other publications, for example because it builds on previous research described in these articles. Citations are also used to position a publication in the overall academic debate within a field, and to frame its contribution vis-à-vis other scholars.

The method is based on the assumption that research which is truly interdisciplinary will, at least to some extent, cite the disciplines that it builds on. We would therefore expect an interdisciplinary publication to cite more disciplines (and to cite them to a greater extent) than a publication, which is written entirely within a specific scientific discipline.

"The interdisciplinarity index" assigns a score to either a single publication or to a group of publications. The value of the score lies in the range between 0 and 1, where 0 indicates monodisciplinarity, and 1 a high level of interdisciplinarity.

The interdisciplinary index is based on three equally weighted dimensions:

- **The degree of variation** in the disciplines cited, that is, the number of disciplines that an article cites. An article that cites many disciplines is considered to be more interdisciplinary than one that cites few disciplines.

- **The balance** between disciplines cited, that is, the relative proportions of the disciplines cited. An article where e.g. two disciplines are cited an equal number of times is considered to be more interdisciplinary than an article, which cites one discipline 90 percent of the time and the other discipline 10 percent of the time.

- **The cognitive distance** between disciplines, that is, how often they are cited together. This is based on the idea that the more rare it is for two disciplines to be cited in the same paper, the more groundbreaking (or, rather, "discipline-breaking") the research that connects them must be. Thus, an article that cites two disciplines, which are normally rarely cited together, is considered more interdisciplinary than one, which cites disciplines that are often cited in the same articles.

[4] *The Web of Science database categorizes scientific journals according to a series of disciplines (or "subject areas") based on their general content; we use these categories to identify the disciplines that a given publication refers to, based on the journals that it cites.*

LIST OF INTERVIEW RESPONDENTS

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Thomas G. Jensen, Head of Department, Department of Biomedicince, Aarhus University (Academia)

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Peter Sandøe, Professor, Institute of Food and Resource Economics and Department of Large Animal Sciences, University of Copenhagen (Academia)

Eric Johansen, Associate Vice President – Science, Chr. Hansen (Industry)

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Claus Dethlefsen, Research Associate Professor, Department of Clinical Medicine, Aarhus University Hospital (Aalborg) (Academia)

Marianne Uhre Jakobsen, Associate Professor, Department of Public Health, Aarhus University (Academia)

Anne Tjønneland, Head of Research, Kost, Gener og Miljø, Danish Cancer Society (Non-profit organization)

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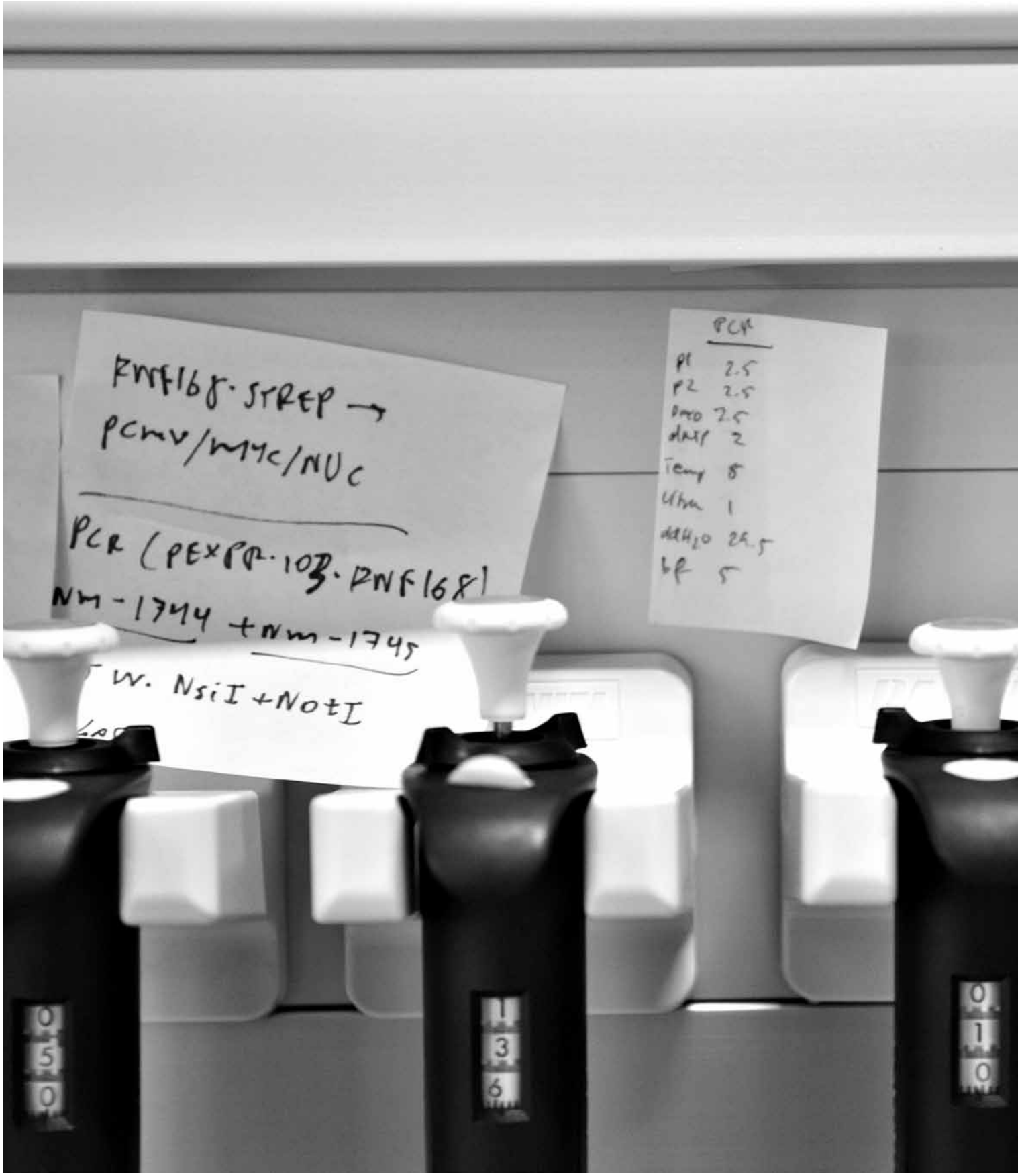
Morten Rask, Associate Professor, Department of Business Administration, Aarhus University (Academia)

Gert Tinggaard Svendsen, Professor, Department of Political Science and Government, Aarhus University (Academia)

Anders N. Andersen, Head of Energy Systems Department, EMD International (Industry)

Jens Rostrup-Nielsen, Head of Research, Haldor Topsøe (Industry)

Arild Underdal, Professor, Department of Political Science, University of Oslo, Norway (Academia)


RNF168 5'-STREP →
PCMV/MYC/NUC
PCR (PEXPR-103-RNF168)
NM-1744 + NM-1745
W. NsiI + NotI
PCR
P1 2.5
P2 2.5
Pmo 2.5
dNTP 2
Temp 8
Ultra 1
dd H2O 22.5
bf 5

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- Challenging the conventional wisdom regarding our work domain

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