Evaluating the societal relevance of research

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Abstract

Scientific research is performed to elucidate how the world around us is functioning. One dimension of the acquired knowledge is that it can be used to develop various sectors of society such as industry, education, governmental practices, the health system or social cohesion. A main characteristic of the so-called societal relevance of research is therefore the quest towards answering questions that society asks or to solve problems it faces. Even though modern societies highly depend on scientific research it is highly disputable how the societal relevance of academic research can (A) be measured and (B) improved. In this review I will discuss these two aspects by means of existing literature. In addition and in order to further highlight recent developments I will present my own results on how different universities have adapted to an increasing "relevance demand" and how communication via social media could become a practical means of science communication. This work therefore intends to be an overview about recent developments and how societal relevance could be formulated in a more robust way in the future by academic institutions.

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Introduction

Humans have always been a curious and limit-seeking species. It is very human to test for borders or improve processes, and ask questions. Research is just the modern framework in which some of these processes are becoming canalized. Research is always also an investment. As with every investment, two desires are connected to it: First of all to maximize high quality results and secondly to decrease the associated risks of performing "unsuccessful" or less relevant research to a minimum. The identification of the societal relevance of research projects is one way to achieve both "investment aims" and therefore to push research into a more fruitful direction by actually creating a measureable benefit for society as a whole or to solve a specific problem with implications for a subgroup of society.

In order to make the definition of societal relevance more clear it is helpful to have a closer look on how the term "scientific impact" could be defined in general and has been defined in the past. First of all research on the interaction between science and society has tried to describe this interaction by identifying special case-based benefits for society (1), but also the usefulness of research for social quality in general (2). However it proved to be difficult to describe the effects of research on society due to a number of reasons: First of all societal impact/relevance becomes easily confused with economic success. Measuring the effects of applied research on an industrial scale is relatively straight forward by focusing on research-payoff revenues or patents whereas evaluating the influence of basic or social science research is not trivial because of its long-term effects (3). Secondly, there is always the possibility that research implications cannot be anticipated or valued at the present time (4), (5). The chances are high that some research projects will only unveil their potential in the future.

After having stated these two factors, it is clear that these traditional approaches can only vaguely describe what science actually means for society. Despite these challenges "measuring the social, cultural, environmental, and economic returns from publicly funded research, be they products or ideas" (4) is still the main component of most science-society interaction research.
Due to the intrinsic problems related to measuring science impact, recently the idea of using knowledge transfer capabilities as a tool has been promoted (6), (7). The underlying thought is that it is more effective to measure and value the sciences ability to communicate with society. Only through communication it is possible that scientific ideas find an application in society.

In this newly arising context, this work has three aims: First of all I would like to introduce the concept and importance of social relevant research to a broader public. In order to highlight the heterogeneity of the field I will present experimental results on how different universities and different scientific fields have responded to society's needs over the years. Secondly, I will discuss different recently used science-impact-measuring approaches by evaluating their strengths and weaknesses. I will especially concentrate on the importance of science communication as stated above and present results obtained by a novel tool that uses the social media to evaluate the spread of scientific ideas. As a third aspect I will discuss how universities might become more able to connect with society. I will especially highlight the strengths of science communication rather than traditional means such as extensive industry-university collaboration.

Different views on societal relevance

In general terms research is often classified into categories such as fundamental and applied research which both take place in academic institutions. A third category is research & development (R&) which often appears in the context of companies. Here, I would like to introduce a simplistic model which describes the interconnection between society and the above described science categories (**Fig. 1**) (8). Classically, the majority of people expect most new knowledge to originate from fundamental research. It is expected that this knowledge consequently "drips down" to categories such as applied research where it finally and hopefully yields benefits for society through industrial application in the case of the natural sciences or for example changed political policies in the case of the social sciences. In **Fig. 1 (A)** this process is symbolized by the big down-facing arrows. However, in reality it is very likely that this relationship is not straightforward. Feedback processes that are based on communication of course occur between the different categories (thin darker arrows). Some feedback mechanisms are very obvious. A company that sells products will for example listen to society's needs. A university applied research department will also be in contact with industry to stream-line their research and receive funding. Whether the fundamental research category is influenced by "downstream" processes is a more open question (symbolized by the question mark), because it is generally assumed that fundamental research is by definition performed independently of economic or social expectations.

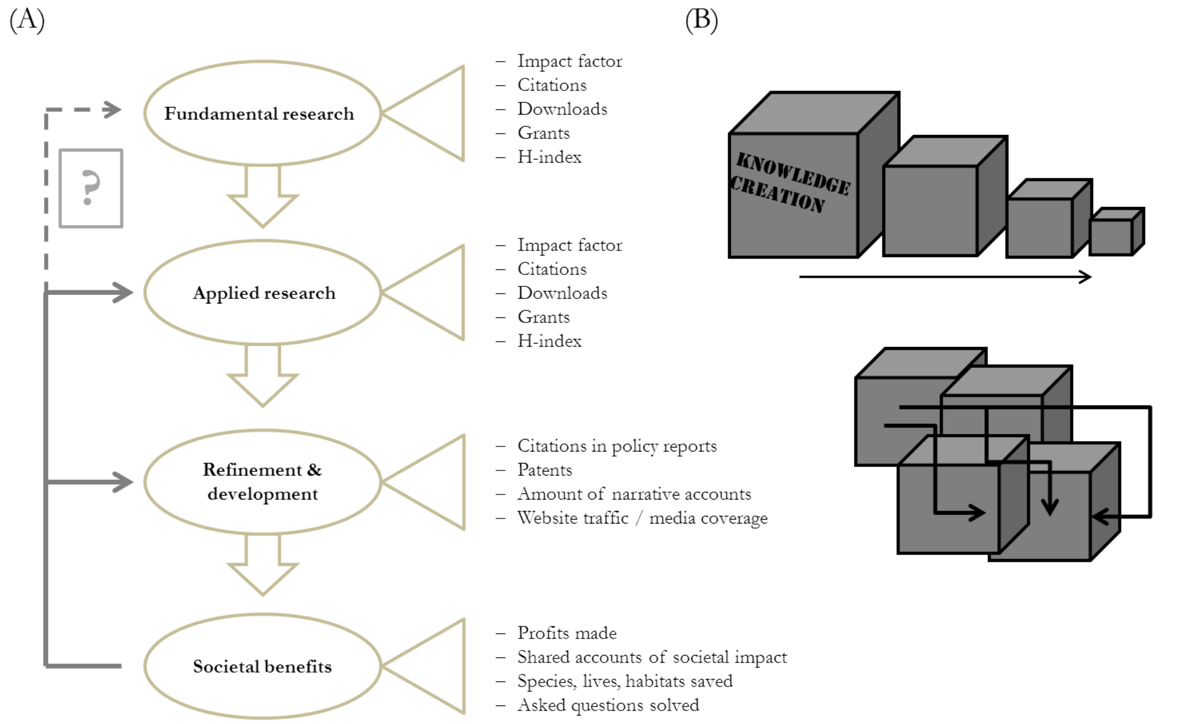

Fig. 1: (A) Conceptual flowchart describing the classical way which "knowledge" has to take through the present system of research management and factors that are presently used to evaluate the impact of every stage. Information is not restricted to linear flow, but feedback from a later level to an earlier one is possible. **(B)** One possible idea concerning knowledge drain through the levels described in **(A)** and a contrary depiction taking into account the dynamics within one level itself and actual knowledge creation on different levels (partially based on (8)). Please see text for details.

All together this linear model results in a scheme as depicted in **Fig. 1 (B, top).** Most knowledge therefore seems to be "created" independently by fundamental researchers and consequently feeds the layers below. The size of the boxes symbolically represents the amount of new knowledge.

However, reality is less simplistic because each of the mentioned categories depends on and benefits from each other. This leads to a scheme as depicted in **Fig. 1 (B, bottom)**. In modern times feedback between all levels is constantly occurring and research fields are becoming increasingly overlapping. A spider web of all levels is the logical result. In other words: basic research depends on results obtained from the applied sciences and the other way round. We can use the Human Genome Project (HGP) during which all the human genetic information was analyzed as an example (9). The HGP was definitely a basic science research project even though a lot of medical expectation were connected to it. However this huge endeavor only became possible because technology was used (DNA sequencing machines) that had been developed previously. In turn the HGP also helped to improve the existing technology. Science is therefore highly interconnected and "knowledge creation" does not only take place on the fundamental science level.

The linear model depicted in **Fig. 1 (B, top)** is especially useful to justify extensive financial support for fundamental research following the reasoning that a broad basis will yield a potentially broad outcome (10). Despite the fact that of course new knowledge is necessary for inventions, the linear model is still only one part of the picture as explained above. Following the same reasoning one could also argue that an increased funding of the applied sciences or even industry, would lead to more potential overlap with fundamental research and therefore more yield, because more "theoretical knowledge" could be developed towards practical applications. Coming back to the HGP: If the technology for sequencing the human genome had been developed earlier the HGP could have been realized earlier. Extensive funding of the applied "downstream sciences" can therefore also have a very positive on "knowledge creation".

Why measuring societal relevance often fails

Science and the benefits it delivers to society can occur on a number of levels and in various manners (see also **Fig. 1**). When trying to evaluate the societal relevance of research it is essential to keep these complex spider web-like dynamics in mind. Otherwise societal relevance will be measured in an ill-defined and very biased manner.

A large number of factors exist that make the evaluation of research relevance a challenging subject: First of all it is difficult to attribute a certain impact to a certain single piece of work. Most present innovations (technological or sociological) are complex as the HGP and must be attributed to several "inventions" which individually have a different weight. Further, counterfactual arguments exist. This means that a certain scientific outcome significantly matches with an effect observed in society and is therefore attributed to it. When looking closer, the relationship is, however, not of a causal nature, but caused by coincidence. Sutherland *et al.* use the example of decreased British greenhouse gas emissions in the 1990s after the general acceptance of human causes for climate change (8). Despite this research on climate change, the observed decrease is presently attributed to a restructured industry which happened due to economic, but not environmental needs (11). Research on climate change, therefore seemed to have an effect, but had no true effect on the reduction of CO_2 emissions in reality. Another, very crucial factor is the time lag between a discovery and its application. This can have two reasons: First, it may need time to implement the findings because of legal and security procedures as in the case of medications, or secondly, the discovery is so fundamental that it needs time before secondarily related findings can be applied to society.

Taking all described factors into account, it becomes clear that certain effects beyond science itself are also responsible for the impact that science can have on society. It would therefore be deeply unfair to purely judge science on its capability to influence society through innovation. Assuming this would be theoretically possible in many cases, in practice a seemingly straightforward connection between science and society can be prevented by some of the above named factors.

The described findings therefore point to the conclusion that scientific relevance measurements need to be performed with great care and unbiased evaluation is difficult. In the following I will explain why the accurate measurement of societal relevance is becoming more and more important even though it is so poorly defined. I will also present new ways of how measuring it could be improved in the future by means of increased science communication.

Why is societal relevance becoming increasingly important?

Many scientists have a critical position towards the evaluation of their research. Still measuring the societal impact of their work will have an increasing effect on successfully completing grant and funding applications. Decisions that European and US science agencies have made in the past point into this direction (12), (13), (14). The reasons for this are multilayered and always need to be examined in the economic and disciplinary context.
In this part of the report I will introduce the economic reasons behind the increasing need to frame research into a societal context. I will limit myself to the situation in the Netherlands and the United States. Generally three categories of research financing sources are established.

First stream: Direct government funding

This first stream of science funding is a form of direct financing. Every year pre-assigned rates dependent on the institution size are paid. For most universities this is the primary financing stream which pays for most positions and everyday basic research. However, the rates are subject to change on a year-to-year basis based on federal budget debates, negotiations, and decisions.

Second stream: Indirect government funding though research organizations

The secondary stream is distributed in a performance-related or performance-expected manner by a single or several research organizations of a country. In the Netherlands this is for example the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) or the European Science Foundation (ESF). In the USA several institutions such as the National Science Foundation (NSF) or the National Institutes of Health (NIH) exist. In both countries these organizations distribute their funds primarily in the form of grants for which researchers can apply. Also the budgets of research organizations are dependent on federal budget decisions.

Third stream: Third-party funding

The last and third stream of science funding originates from private, company or other non-governmental/profit organizational funds. Most of the time funding is performance related and applications are required. Concrete expectations concerning certain outcomes are frequently attached to grants. As a consequence basic research is only seldom funded by third stream financing. The amount of available funds depends on the economic situation and the willingness of the organizations to fund research. It is independent from federal budget decisions.

Formulating a social relevance factor for their research has become increasingly important for scientists when applying for especially second and third stream funding in Europe and the USA (12). Why is this the case? For every financing stream I worked out a major reason why choices have to be made in an increasing manner and *why the formulation of societal benefits is so essential.*

First stream challenges: Financial restrictions

Science budgets are fluctuating in the USA and are even decreasing in the Netherlands (**Fig. 2**) over a period from 1996 to 2010 when considering the relative amount in comparison to the overall economic strengths of the countries. The economic strength of a country is expressed by its gross domestic product (GDP). Uncertainties concerning the future economic situation and the cutting of budgets in general have caused this trend. It is, however, remarkable that the relative amount is so vulnerable. One conclusion from these facts is that the importance of science funding is declining with respect towards other budget options such as economic affairs, health care, and social protection. This trend is very clear for the 27 members of the European Union (15) and is likely to be similar in the USA.

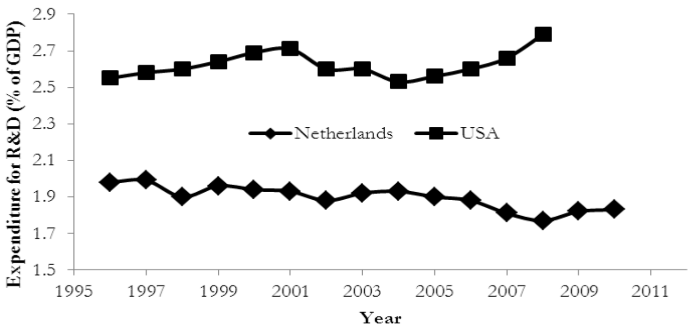

Fig. 2: Federal spending in the form of especially first and second stream funding on research and development in the Netherlands and the USA from 1996 to 2010 as percentage of the respective country's economic strength (gross domestic product = GDP) (Source: based on Eurostat data).

Vince Cable, who is Britain's minister for business, innovation, and skills, urged scientists to perform "more with less" (16). However, as budgets are increasingly under pressure it becomes more and more important for researchers and universities to highlight the significance of scientific research with a strong voice. More understanding of the societal relevance of research will make arguments from academic institutions stronger when it comes to budget decisions, because the well-being of society, technical innovation and the economic strength of a country can directly be tied to scientific research. It proved difficult to obtain data on which scientific disciplines suffer the most from limited research budgets. However, at least for he United Kingdom there is evidence that since the 2008 recession social science was disproportionately affected for funding cuts as when compared to the natural sciences (17), (18). Even attempts have been made to cut federal funding for the political sciences altogether through not allowing the American National Science Foundation (NSF) to fund this discipline anymore (19). Because of this extreme pressure that some scientific disciplines have to face, it becomes even more important for them to be able to explain the relevance of their work, for example by founding lobby groups that openly communicate scientific value to decision makers.

Second stream challenges: Grant systems

A so-called "broader-impacts" criterion has been introduced for National Science Foundation (NSF) grant applications in the USA (13). Importantly, since January 2013 standard publications are *not* the only means to assess research quality anymore (6). In the Netherlands a similar approach is followed. Research is assessed based on its societal relevance since 2009 by the ERiC (Evaluating Research in Context) commission, which is a joined effort of all the big science players in the Netherlands (HBO-raad, KNAW, NWO, VSNU, and Rathenau Institute) to optimize grant distributions to researchers. All research in the Netherlands is evaluated by this commission and societal relevance is one of four key aspects during the visits and the evaluation process (14). Especially concerning second stream funding these developments demonstrate how important it is for researchers of all disciplines to express commitment towards the societal relevance of their work.

Third stream challenges: Collaboration between businesses and science

As the pressure on the in essence federally organized first and second streams rises, the independent third stream of non-governmental science financing gains significance. However, non-governmental organizations are, with a few exceptions, very likely to only support projects where a benefit can be expected in the near future. While these benefits can span different disciplines they are almost always linked to a societal benefit due to direct innovation. Even though the situation is improving, many universities still lack the strategies, leadership or business models to fully benefit from interactions between the university and non-governmental/business world (20). It has been proposed in the past that third stream science financing is just another form of generating benefits for society through research (4). I doubt this because third stream funding is often tightly connected to result expectations and business financial gains that have no direct positive effect on society. Despite this criticism it is important for universities to boost their budgets by creating "societal relevance" plans which make it easier for non-governmental financers to profit from the knowledge base that research institutions have created in the past. If universities wish to benefit from the monetary strength of industry or other organizations, they must engage in programs which clearly state what the university has to offer to external partners. Programs could include, but are not limited to:

- Formulating areas of scientific expertise in a clear, accurate, attractive, and understandable manner
- Strengthening ties with non-academic institutions through student internship placements and thesis supervisions
- Creation of a network by for example actively inviting representatives to attend academic life
- Promote the creation of a framework that allows legal and financial security for both partners during the collaboration (to avoid patent lawsuits)

The long-term implementations of these ideas will universities to identify research fields that will drastically increase a university's attractiveness for many external partners, and the public. In summary it can be stated that it is necessary to demonstrate the present day need to embed science in a context which has relevance for society. Here, this need is mainly attached to financial incentives regarding the three streams of science financing.

How does societal relevance differ in a number of fields or between universities?

Obviously some scientific disciplines face fewer challenges in demonstrating how their research has an impact on society. Interestingly, these disciplines are especially the natural sciences including engineering and informatics, probably because of their historic tie with industry. The social sciences which results could have a direct effect on society, seem to face more difficulties in demonstrating this usability (17), (18), (19). It is possible that during grant applications a bias exists towards the economic usability and applicability of research findings. This would mean that especially scientific output (in the form of journal publication) of economically relevant topics from the natural sciences would increase over the years. Research in the social sciences would therefore increase to a smaller extend. Because I could not find information in the literature on how societal relevance changed over time, in different fields and among different universities I decided to design a study myself to investigate these relationships.

In order to test whether universities adapted to the increasing pressure to engage more in research that is important for society I performed an data analysis with the help of the scientific database ScienceDirect (21). ScienceDirect is an online repository operated by the Dutch publisher Elsevier and currently contains 11 million scientific publications by 2,500 scientific journals. This search engine is therefore a very attractive tool to trace scientific development over time, in different fields, and among different institutions.

In total I analyzed the publication output of six different universities from three countries which fall into two different general categories and which belong to either the top, the middle, or the bottom 10% of the 2012-2013 Times Higher Education (THE) university ranking (22) (**Tab. 1**). In order to find out how the needs of society influenced the number of publications of all six institutions, I compared the publication output of the period from 1991-2001 with the period from 2002-2012 by using a number of search terms that are related to problems that societies face. Societies of course have to deal with a large number of problems and therefore I had to limit myself to research challenges that have been proposed by the European Commission (23). Searching the database ScienceDirect for the terms mentioned in **Tab. 1** (demographic change, health and ageing, etc.) in combination with the two mentioned time periods yielded one publication output number per period and per search term. This analysis was repeated for each of the six universities.

The following example shows how the numbers (= factors) that are mentioned in **Tab. 1** were obtained:

> *A search of the ScienceDirect catalogue with the term "demographic change", researcher affiliation "Harvard University", and for the period from 1991-2001 yielded 492 scientific articles. Repetition of the same search, but now for the period from 2002-2012, resulted in 2,411 found scientific articles. Publications written by Harvard researchers on "demographic change" therefore increased by factor 5 from 1991-2001 to 2002-2012, because 2411/492 ≈ 5. This number can be found back in* ***Tab. 1****.*

In addition I used the search term "wireless" to have a comparison how strong the change in publication numbers is because wireless internet devices where almost non-existent in the period from 1991-2001. Marked in red are all factors that are higher or at the average of their respective category.

Tab. 1: Overview of scientific journal publication output change from 1991-2001 to 2002-2012 period (by factor). Included are six universities, their THE (Times Higher Education) rank, and ten different search queries. The number of "fields" in which the publications of the institution increased at or above average are highlighted in red color. CIT = California Institute of Technology. Raw data can be found in Supplementary Materials.

	General Universities			*Technical Universities*			
	Harvard	Groningen	Frankfurt	CIT	München	Twente	Average factor
THES rank	4	89	199	1	105	187	
Demographic change	5	5	9	8	9	10	8
Health, ageing	5	4	5	5	7	12	6
Sustainable agriculture	3	5	20	10	9	10	9
Renewable energy	5	5	10	4	9	9	7
Logistics, transport	6	4	10	4	3	4	5
Immigration	3	3	5	3	7	14	6
Social mobility	3	3	5	4	21	4	7
Education, school	4	5	13	2	6	3	6
Climate change	4	3	9	4	6	7	6
Wireless	11	15	8	12	14	16	13
Above or Average scores	1	1	6	2	9	7	

Even though my selection includes only a relatively small number of universities and arbitrary type of search terms a number of conclusions can be drawn from the data. It seems that general universities and top-ranking universities which have quality research programs in a number of scientific fields have produced a relatively constant growth of publications in the observed timespan when compared to lower ranking and technical universities. This observation can have several reasons: First of all it might be a purely random effect based on the small number of universities. But secondly, it could also mean that general and high-ranking universities have always been strongly interested in research that is important for society. Therefore the observed change in publication numbers over time is relatively small in comparison to the other universities. Another implication can be that technical universities and lower ranking universities are more flexible in adapting their research foci towards changing social demands. Interestingly, this also seems to be case for non-natural sciences related topics. Moreover it is possible that especially lower ranking universities are increasingly forced to shift more towards research that serves a "need" in order to receive sufficient funding as discussed in the previous sections. High-ranking universities might not face this pressure. When comparing the scientific fields with each other, it becomes obvious that especially social science related topics such as demographic change, sustainability, or social mobility publication numbers have increased. In addition renewable energy seems to be a topic of increasing interest. Based on my findings I *cannot* conclude that a strong bias seems to exist that leads to a significantly higher publications output in research areas that are dominated by the natural sciences. It even seems to be the case that some social science related topics have gained extreme importance during the last decade.

As the results in **Tab. 1** indicate, especially large and broadly oriented universities might face challenges in quickly adapting to key problems of society. However, in order to stay competitive it is essential for this category of universities to identify these topics and invest in research. The University of Groningen, for example, is trying to cope with society's demand for solutions by implementing different long-term strategic aims. Within the three key themes Healthy Ageing, Energy, and Sustainable Society the university aims to excel. The first part of the strategic plan is implemented between 2010 and 2015 and has already had a profound impact on the city and the university. With the help of national and European Union science funding the European Research Institute for the Biology of Ageing (ERIBA) and the Energy Academy have been founded. Both institutions offer completely new or changed Bachelor and Master courses and degrees. There is also close cooperation with industrial partners, as well as a tight connection to the exisitng university infrastrucutre and regulalry public outreach events are organized. Most importantly these initiaves were designed to be interdiciplinary projects. The Energy Academy, for example, does not only cover engineering research, but at the same times investigates the social impacts of a changing energy sector towards a "greener" economy.

Tab. 1 might therefore be used to formulate general guidelines for universities to optimize their research strategy. Since there are strong differences between the universities concerning research that has a direct relevance for society it might be beneficial for some universities to strengthen their position in socially relevant fields which will likely contribute to increase funding. Low-ranking and technical universities might be more flexible in adapting their research programs. The example of the University of Groningen, however, shows that also relatively large and broadly organized universities can adapt to changes in society by carefully identifying key areas of interest and linking them to the existing expertise and infrastructure.

Further, I wanted to know more generally how the six universities named above are represented in everyday day life and people's perception. The internet has become a large repository with lots of information originating from different aspects of life. Therefore, I used the Google search engine to (A) measure how often the name of a university appeared online and (B) how often the universities name is mentioned in the context of innovation (**Fig. 3**).

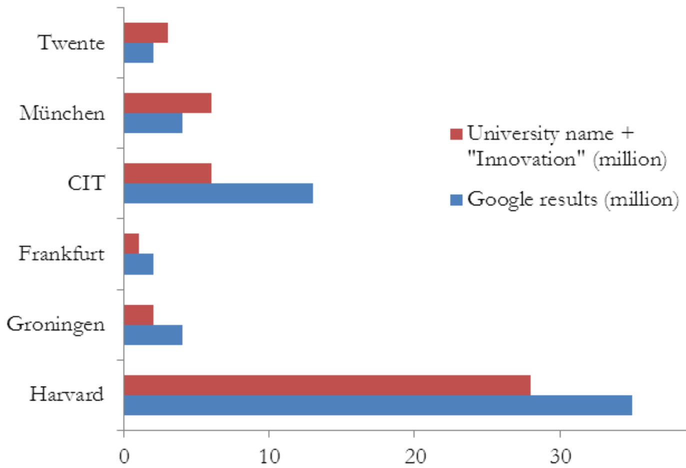

Fig. 3: Results (in million results) for two Google searches in January 2012 on six different universities. To a certain extend Google has become a convenient tool to investigate the penetration of information through modern western societies. The underlying search algorithm can lead to effects that searching for two terms (red) can lead to more results than searching for one term only (blue).

Of course a Google search does not perfectly correlate with the true societal impact of a university. Still, the results are interesting. Technical universities seem to be perceived as more innovative and seem to be represented in a better way in the internet than comparable general universities. Harvard University is disproportionally represented in **Fig. 3**, but also has a large effect on the American and European societies in real life due to its large financial capabilities and attractiveness for researchers who are experts in their respective field. The same holds true for the California Institute of Technology. The number of alumni of both universities who have won Nobel prices, have important roles in politics and culture, as well as being the founders of very innovative and/or large companies is impressive. Both universities have succeeded in directly or indirectly entering the lives of a lot of people and therefore society as whole through products, political decisions, and groundbreaking scientific studies.

An important question to ask is how the other 99% less prestigious universities can enhance their presence in debate and everyday life. Of course academic success and innovative research are a perquisite and necessity, but also universities that do not have enormous prestige can succeed. In order to strengthen the universities perception in people's minds it is important to manage their alumni. American universities are very good at setting up networks and events for their alumni. Thereby they are becoming more anchored in society, through for example presence in media and active science communication. American universities also tend to be "proud" of their alumni and their achievements. European universities are just starting to realize the values of their former students.

Is societal relevance measureable?

Research impact on society is measureable. The challenge is to perform these analyses in an objective manner and the history of impact research has shown that this is very difficult. Measuring the impact of science in general has traditionally been a challenging and controversial process. It has its roots in the 1950s when federal agencies tried to assess whether investing in one project would in the end be more profitable than in another one. Later also private organizations such as aid agencies or philanthropists became interested in the idea of maximizing the impact of their investments (24). Even though databases with models, approaches and theories concerning the best tactics do exist and are ever expanding, the root of the problem has not been tackled so far: Societal impact is not a black-and-white issue and its complexity is mainly based on human subjectivity of data collection and result expectations. "The society" might exist in theory, but in reality this construct consists out of different age groups, people with different capabilities and ambitions, financial restraints and welfare necessities, cultural and political differences, and many additional factors. The dilemma therefore can be sketched as follows: Either an assessment approach covers "society" in general by measuring economic/financial changes or other rather universal factors, or the approach is focused on a smaller target group and their specific problems and needs. In any way compromises need to be made.

Large collections and repositories of general impact-measurement approaches can be found in specific databases (25), in government reports ((1), (14), (26)), or in recent scientific literature ((8), (27)). **Tab. 2** summarizes the most commonly used ones. Despite their wide spread use the notion of scientific impact is a multi-dimensional construct that can not be adequately measured by a single indicator (28). Therefore **Tab. 2** also briefly mentiones the shortcommings of each method. Researchers are consequently often evalauted by their ability to work at a certain institution or publsih in prestigious journals.

Tab. 2: Brief overview of standard methods to assess the quality of scientific journals, universities and as a consequence also researchers (28).

Method	Description	Weaknesses
Journal impact factor	A 2 year average per-article citation rate of a journal, i.e. the average number of times articles that were published in a journal in 2004 and 2005 were cited in 2006.	Journal editors might apply measures that artificially raise their journal's impact factor.
Hirsch-index (H-index)	A scientist has index h if h of his/her N papers have at least h citations each, and the other (N − h) papers have no more than h citations each.	It does not account for the number of authors. Also the context is not considered (reviews contain many citations for example).
University rankings	Many different variants exist. Most measure the productivity of the scientists, the reputation of the institution, the level of internationalization, the number of patents and/or Nobel prizes and other prestigious awards.	A ranking can never account for all factors because universities are very different with different focus areas. Subjective "reputation" often still plays a major role.
Eigenfactor	Journals are rated based on the incoming citations. Citations from more prestigious journals lead to a higher Eigenfactor.	The outcome is influenced by the size of the journal from year to year. A growing journal will have higher outcomes over time.

However, in this section I will concentrate on new and innovative approaches concerning the measurement of science impact on society. In the following I present three different approaches and discuss their strengths and weaknesses. However

1. Society and its questions

One approach to find out societal relevance is actually a reverse approach and contains two steps. This means that one would first identify certain problems that society is facing (climate change, cancer, etc.) and secondly evaluate researchers based on their ability to work or even solve these challenges. In fact I used a similar approach to evaluate how different universities cope with some important problems (**Tab. 1**). However, this method was originally intended to elucidate whether research "answers questions of interest to research end users" (8) and consequently had a broad application base. Sutherland *et al.* asked the question by which actions bee populations could be preserved the best. In the following they collected 149 scientific papers, 4 reports, 3 books, and 3 PhD theses which they expected to be helpful for answering their question. Then they attributed a score to every single publication related to how helpful it was to improve the conservation of bees. Publications that indicated that a certain measure *does not* work were also considered as a useful contribution towards answering the question. Interestingly, the researchers could develop a final list which describes ten approaches in total that might be beneficial. This method of analyzing research products, however, has a number of pitfalls. First of all clear question needs to be asked. "How can be bees be preserved the best?" is such a question because it is actually testable. To ask which measures might help to reduce the demographic shift in modern western societies, might not be a good question in this context because only hypotheses exist and it is not possible to experimentally test such a hypothesis with regard to the future. In addition the publication selection is very subjective and there might be a bias towards applied research by missing out theoretical work that has unexpected usability. Furthermore, the method is extremely labor intensive and time consuming especially for questions for which much more publications exist, such a medical challenges. The authors themselves conclude that "we do not suggest that our approach becomes a standard means of assessing impact". Even though the method might be impractical for everyday application and large impact screenings, it still represents an extremely well thought through approach which nevertheless might help to understand how important scientific research is to solve real-world problems. In the future it might therefore helpful to identify key questions and specifically evaluate researchers based on what they contribute towards answering this question.

2. Measuring the return of science investments

The other path one can take to evaluate the societal relevance of research is to formulate conditions which should be met by successful research endeavors. Next to harvesting traditional publication numbers, citation scores, and patents, Lane and Bertuzzi propose to include broader outcomes such as better health, clean energy, training of a competitive workforce, or increased competitiveness (29). Their intent is to leverage digital technology to capture these and more broad scientific impacts. According to them the key to gather all these non-related and widely distributed information is the construction of a massive data infrastructure system termed STAR METRICS (Science and Technology for America's Reinvestment: Measuring the Effects of Research on Innovation, Competitiveness, and Science). The plan is to combine public and private databases with stakeholder expectations and thereby combine all available data that might be beneficial into one database. The whole approach, however, is confronted which huge challenges that first need to be overcome. These are mainly of practical nature: How can databases of federal agencies become combined with company and university records? What should be included, and what not? What is classified as a "science impact" and where should you draw the line? Are short-term analyses trustworthy? Currently, the STAR METRICS approach leads to more questions than answers and important issues such as the consulting of all engaged parties have not been resolved. Despite all this, I consider STAR METRICS to be an interesting approach because it combines various information sources with each other and asks the seemingly easy question how large the effect of science funding is on the evaluated parameters.

3. Conservative research assessment

Even though STAR METRICS sounds very ambitious, large data collection through digital repositories might become easier form a technical perspective in the future. Several tools such as Web of Science, Google Scholar, or Webometrics already exist. Currently they do, however, not cover all scientific findings that exist. Therefore, in addition to the two previously described rather new and specialized approaches it is helpful to assess the impact of research on society by a number of more traditional means (26).

Contacting researchers and their institutions directly

In, for example Australia, a nationwide organization links the interests of researchers with the interests of citizens and other stakeholders who are affected by this research. This Research Quality Framework (RQF) which has been renamed Excellence in Research for Australia (ERA) in 2008 uses a combination of metrics and expert review in order to create transparency and stimulate mutual interactions between society's needs and academic and industrial research. However, this ambitious plan has also been criticized since it has been claimed that "commercial research undertaken by publicly funded research agencies needs to be handled differently to academic research" due to fundamental differences such as the fact that "[industrial research] cannot be submitted to a peer review mechanism" (30). Because the ERA metrics heavily depend on citations scores and similar indicators real objectivity can currently not be guaranteed.

Researcher-researcher assessment

These so-called peer-review panels are present in several European countries and especially have a tradition in the Netherlands. The panels consist of international experts who physically visit universities and talk to researchers in person. Even though this approach seems quite subjective on first sight, studies find it to be extremely effective in hindsight (31). During a typical two-day visit the expert panel listens to poster presentations, interviews researchers in different positions and assesses the research infrastructure. This rather qualitative than quantitative approach finally yields a high, medium, or low impact estimation. Interestingly most big science players such as Australia, the UK, but also the Netherlands are increasingly relying on this method against the electronical bibliometric trend (32).

Indicators, purpose, and self-assessment

Fine tuning all three factors together in quantitative rather than qualitative approaches has shown to deliver better results than just primarily focusing on one of the factors. *Indicators* include measureable elements that can indicate change due to science impact. Because of its ease of use bibliometric data are widely applied. Less known indicators concentrate more on time aspects such as retrospective and prospective analysis of research impact. These impacts can then be measured by other factors as well, such as economic change or increased health and satisfaction in life. Especially the Dutch research assessment framework has its focus on retrospective/prospective analysis (1). A third form of an indicator is the already mentioned aspect of peer-review. Quantitative studies are also frequently *purpose driven* in order to reduce the complexity of the available datasets. Logically the general purpose in most cases is the improvement of research in conjunction with a maximization of positive impacts on society. Achieving both at the same time is, however, very complicated and probably not realistic. Different countries therefore handle different focus areas. The prime focus of US and UK assessments is to optimize the distribution available resources, the Dutch aim is very concrete and deals especially with the direct improvement of research quality ((1), (14), (26)). Some countries, including the Netherlands, include *self-evaluation* as the third important factor into their assessment approaches (26) in order to include an element into the judgment process which is not governed form outside, but more reflects the view of the institution on itself.

General principles for designing a successful assessment method

The presentation of the three assessment methods above showed that they all have individual strengths, but also weaknesses that prevent them from being the single method of choice. In the future a successful societal relevance assessment method could be designed that includes some of the elements of every method. **Fig. 4** depicts a system that I designed based on the above presented methods. It consists out of three elements: A question identifier component, a neutral statistics component, and a personal assessment component. The aim is that the strengths of every individual component can compensate for the weaknesses of others.

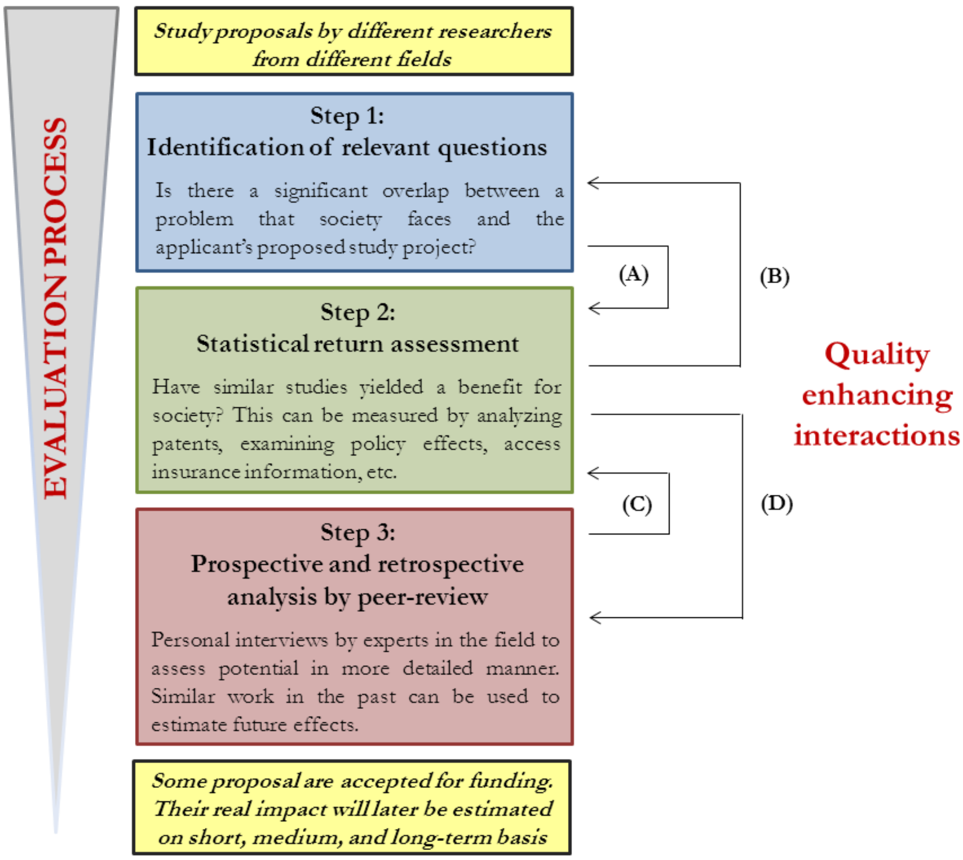

Fig. 4: Proposed three-component model that could enable universities and government agencies to estimate the social impact of academic research in a more efficient way. The three components are individually discussed in the previous section, but enhance each other's usability when used together (A-D).

A major adavantage of the above described model are the interactions between the three steps that will likely enhance the overall quality of the outcome. Interaction (A) for example makes the statistical analysis in step 2 more reliable, realistic, and easier because only relevant aspects are tested that were identified in step 1. In turn interaction (B) helps to sort out (or gives lower priority to) projects that are statistically non-testable. In addition if research projects seem to have a low "life quality" effect they might receive a lower priority. Interaction (C) is very important because it tries to identify novel ideas that are very promising, but for which no statistical evidence exists yet. It is logical that this evaluation step is very subjective, but pure statistical analysis might prevent funding of very new and innovative work. Interaction (D) is a last check that guarantees that errors are kept to a minimum. Research ideas that likely will not make economic, medical or social sense based on statistical analysis in step 2 can be looked at in more detail to possibly identify relevance in step 3.

A disadvantage of the proposed three-component system is that younger scientists are likely to score lower in some areas because they did not have enough time to identify their own research niche. Despite this, it is important to emphasize that my proposed method is not focused on evaluating individual scientists, but focused on evaluating the likelihood that a research idea will result in a positive outcome for society. Therefore, being young and having new innovative ideas that can be placed into an existing context can also be an advantage. Through understanding the proposed model young researchers can also start to develop a feeling for important problems that society faces and how they could be efficiently targeted by research projects.

Whether these research projects will later yield a real benefit is of course never 100% predictable. Despite this, young scientists need to start to consider the impact and likelihood of possible results of their work. By initiating this learning process society and science would already move a large step forward.

How could the sciences achieve more societal relevance?

As has been stated before, the societal relevance of research is an extremely subjective field. What can be considered *relevant* changes from time to time and from interest group to interest group? To find common ground seems to be very difficult. It might be helpful to take a step back and concentrate on the bare essence of societal relevance. This relevance is centered on knowledge and information transfer, but also the transfer of wishes and desires between the academic ivory tower and the "real world". In this chapter I will *not* extensively discuss how this knowledge transfer could be organized more efficiently with all its facets. Here I would like to promote the concept of ***friction surface creation*** between the two worlds. In my opinion a true understanding of society by science and the other way around can only be achieved by creating interactions on all levels and encouraging discussions. Three different approaches that aim at a better communication between science and society have been proposed recently.

1. *Value all research products*

In times of the internet and large databases it is not difficult to analyze electronic resources as described above by for example the STAR METRICS approach. The challenge is, however, to be selective and only choose data which likely has a causal and direct relationship between research and societal impact.

An interesting recent approach is linked to new funding policies of the NSF. This policy states that research products "must be citable and accessible including but not limited to publications, data sets, software, patents, and copyrights" (33). This new and intentionally broad definition of research products opens up new room to assess research impact on society. The informatics researcher Heather Piwowar has formulated a strategy to evaluate the overall production of scientists and not only their publications (6). She proposes the use of specialized search engines that for example track the number of downloads of all kind of scientific files including figures and videos. An even more extensive approach is followed by the websites *Altmetric.com* or *Impactstory.com*. Both websites are specialized search engines. They are able to search for scientific articles that are mentioned in "blog posts, tweets, and mainstream media".
To my knowledge *Altmetrics.com* has never been used to compare the presence of research from different fields in different social media. It offers an interesting possibility to test how scientists interact with modern media and thereby create direct ties with society and communicate their work.

In the following I will describe results concerning the practicability of the altmetric (= *all metrics*) approach for a number of search terms that are similar to the ones used in **Tab. 1**. In addition this experiment demonstrated that the internet and alternative forms of publication are an excellent way of creating public awareness and appreciation for scientific research. Facebook, Twitter and internet blogs for the first time in history enable a straightforward communication of researchers with the public. **Fig. 5** displays the results of an analysis performed with the *Altmetrics.com* tool (34). At the heart of this tool lies a search algorithm which is able to find scientific papers in social networks, blogs, and news websites. This process is based on the so-called Digital Object Identifier (DOI) number of the publication. Every scientific article that is accessible in a digital form has a standardized DOI number. The DOI number makes searching for a specific article very convenient without having to use the entire title or author names. The following methodology was applied to obtain the described results:

The search engine PubMed was used to identify scientific articles that contain the keywords mentioned in ***Fig. 5*** *(colors) and that were published between August and December 2012 in the three journals Nature, Science, and PNAS (Proceedings of the National Academy of Sciences of the USA). These three journals are generally regarded as very prestigious and publish research from all scientific fields. I chose them because all three journals usually contain ground-breaking work which is expected to lead to a significant response in social networks and the internet in general. In total 59 articles were found. This is an average of 15 papers per category. During the next step the DOI number of every publication was entered on Altmetrics.com. This search engine then scanned through blog posts, Twitter, Facebook and mainstream media such as news websites.* ***Fig. 5*** *shows the results of this search. Per category (color) a different number of articles were found on Facebook, Twitter, etc. This average number is termed "average frequency" in* ***Fig. 5****.*

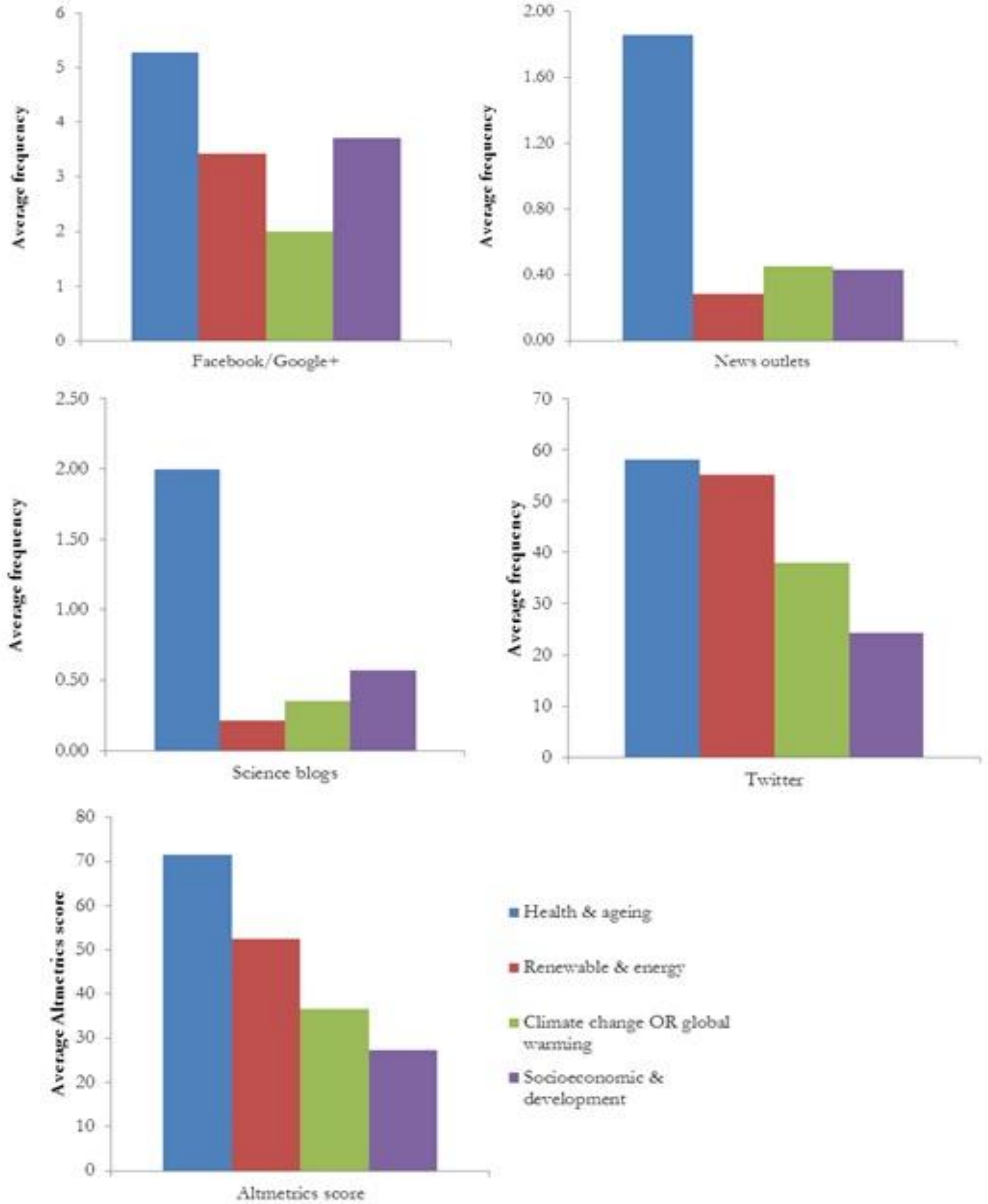

Fig. 5: Results of an Altmetrics analysis. First, all scientific papers containing the above mentioned keywords (blue, red, green, purple) that were published in the Nature, Science, or PNAS high-ranking journals between August and December 2012 were identified by the search engine PubMed (35). 59 publications were found in total (≈ 15 per

category). Please refer to the text for more detail. Raw data can be found in Supplementary Materials.

As depicted in **Fig. 5** especially Twitter seems to play an important role in distributing current research findings to the public. Roughly 20 to 60 times each article is mentioned on average on Twitter. Facebook seems to play a minor role and articles are only mentioned between 2 and 5 times on average. Facebook and Twitter are, however, relatively easy to use social networks and therefore it is convenient to use them to mention articles only very briefly, to discuss findings or to raise awareness of the results. News outlets such as online versions of newspapers and internet blogs usually report on scientific findings in a more extensive manner. Only some articles are therefore discussed by these media. In addition far less blogs and news sites exist than Twitter or Facebook accounts. Furthermore, it is interesting to see how frequent scientific topics with a connection to societal issues are discussed on the internet depending on their topic. In general especially the topic health & ageing seems to be very attractive and widely discussed. Research dealing with the socioeconomic situation and development receives far less attention. The so-called "Altmetrics score" was developed in order to be able to compare the resonance of different publications as a whole. Each category contributes a different amount to the final altmetric score. For example, a newspaper article contributes more than a blog post which contributes more than a Twitter message. The Altmetrics score proves that health and ageing seem to attract the most attention, followed by energy and climate change related issues. Socioeconomic research is represented to a smaller extent.

In conclusion, the observed effects of course largely depend on the chosen keywords, the time frame and the chosen journals. Therefore the results are not objective enough to draw detailed conclusions. Due to practical and data volume reasons it was necessary to limit myself to this approach. Still, general trends that are often hypothesized can be extracted from this dataset. Biomedical topics receive a lot of attention in the internet and probably also in society. Furthermore, technical topics and climate change have a large impact on public opinion. Research that directly deals with humans and our society, however, receives a remarkably smaller amount of attention. This is a challenge that researchers should definitely counteract in the future. The social sciences are a key science in resolving many present day problems such as demographic problems, the declining middle class/rising poverty, successful integration of minorities, responsible economics, and several other topics.

Based on my results I propose that especially economics, humanities, and social science researchers need to be more proactive in communicating their research, especially by modern media such as Twitter which will raise the attention level and will likely also result in more newspaper articles and consequently increased public awareness.

2. More interaction between researchers and society

The internet is, however, not the only way for researchers to create more interaction with society. In my opinion scientists also increase the societal relevance of their work by direct personal action, or at least increase the chance that their results will have a permanent impact on the lives of other people. By creating more "friction surface" between society and science citizens will start to appreciate the researchers work because of a gradual increase of understanding. Furthermore, by creating more interaction it becomes much more likely that other scientists from different fields, entrepreneurs, or even ordinary people will recognize potential that would otherwise have gone unnoticed. In a recent publication Thomas Pollard calls scientists to action by proposing a number of measures how scientists can improve the societal awareness of their work (36). **Tab. 3** summarizes his proposals in a generalized way. Even though these incentives were originally formulated to increase political awareness for biomedical funding, I consider them also attractive for science in general.

Tab. 3: Overview of proposals on how researchers can increase the interaction between science and society by different means (partially based on (36)).

Proposal	Details	Pros & Cons
Join a professional society with an advocacy program	Increased voice of the organization and financial support, also personal benefits such as mentoring	Pros: Easily achievable, large-scale effectiveness Cons: Rather passive, no direct impact on society
Join a grassroots advocacy network	Volunteer for positions within the organization, take direct action such as discussing matters with officials	Pros: Creative input, many possibilities, direct action, already a few contacts can have impact Cons: Not one strong voice, danger of inconsistency
Volunteer to advocate science	Recruit colleagues, parents, friends, students, professors, post-docs, technical staff to create a scientific voice	Pros: Direct science-society link, creation of broad base Cons: Actions can unspecific, complex setup
Visit elected officials	Join society visits to the capital, introduce yourself directly, make personal appointments concerning concrete matters	Pros: Direct action, close to relevant policy makers, high impact Cons: Strong self-initiative and will required, certain job positions might be beneficial
Inform elected officials about grant applications and financing and science in general	Politician are always asked for money, but rarely see the actual results, open eyes for everyday challenges and also small-impact results	Pros: Direct action, close to relevant policy makers, impact, increased communication Cons: Strong self-initiative and will required, well thought argumentation necessary
Support political candidates who appreciate society-science interactions	Collect information on candidates websites and in newspapers, participate on a local level	Pros: Long-term impact Cons: Time intensive, no clear or desired outcome possible
Take part in community outreach projects	Inform general public about the relevance of concrete research projects for society, appreciate taxpayers money	Pros: Direct and high impact Cons: Relatively high workload, local impact
Invite "outsiders" to workplace		Pros: Impact on policy makers, long-lasting impression Cons: Coordination required, intensive preparation
Consider career in science policy	Become a science policy advisor and spend some time in the capital	Pros: Expert impact, direct action, long-term effects, coordinated, career change Cons: Long-term commitment, career change, strategy required

By active engagement into debate and discussion different scientific disciplines will therefore create a broader base to operate from and will offer insights into science for the public. The sharing of knowledge, in my understanding, is already an important impact factor of science on society, but there is still a lot of potential to improve the quantity and quality.

3. Promotion of student networking

So far a few proposals have been discussed concerning the role of experienced researchers or even professors. Despite their essential role, in the long run it will be the present students who will have to create a better science-society interaction. In order to promote such an early interaction the Canadian York University has founded the Knowledge Mobilization Unit (KMb Unit) (37). This organization is the first of its kind which follows a structured approach to motivate students form early on to take part in language training in order to become able to summarize latest research findings and make their own research more accessible by a number of communication strategies including newspaper articles, the internet, presentations and many more. An additional element of the strategy is the sponsoring of internships for advanced level students during which they can work in non-academic institutions which are related to their field of study. Personally I consider this approach very valuable and it is relatively easy to adapt. Maybe in the future more universities will engage in similar programs. Further, I believe there is a maximum profit for students. They will learn how to organize their career, how to make certain choices, they will become more proactive and more able to put themselves in the position of people who have not studied what they have studied. These are the real life situation that students need to learn to cope with. Producing one theoretical scientific paper after the other will not suffice.

Conclusion

This work intends to serve as an overview on recent developments concerning the applicability of scientific research for the good of society. After a description on which levels science and society interact and how knowledge is "created" (**Fig. 1**), the increasing importance of societal relevance for academic research has been highlighted. During the last decade the economy has pressured federal science budgets. This led to an increased competition among researchers. Even though the publication output in research areas that concern societal challenges seems to be comparable between the natural and the social sciences (**Tab. 1**), a threat exists that declining science budgets might hit the humanities and social sciences the hardest ((17), (18), (19)). As demonstrated in this work, the first, second and third science funding streams all have a close and increasing connection to societal relevance (12). Therefore the expression of a societal benefit criterion is very important for researchers. The need to express the relevance of their work leads to two important questions that were both addressed here. First, how can relevance be measured in a robust manner? Secondly, if societal relevance is understood in an appropriate way, how can this knowledge be used to increase the benefit that society can gain from science?

Concerning the first question it is important to note that traditional and "hard means" of research assessment such as the impact factor, H-index, and citation scores have the potential to distort science because only highly spectacular results are valued. Recently even a bias of "positive results" (confirming the hypothesis) over seemingly "negative results" has been observed (38). "Positive results" are significantly cited more often than results that proof that something *does not* work. Furthermore, the current publication practice in general has been criticized in the past, because it distorts scientific integrity by encouraging economic-like behavior which means that scientists more and more react to "needs" that are introduced by large publishers instead of independently formulating their hypotheses (39). In order to avoid making the same mistakes when assessing scientific societal relevance, in this work three new and innovative approaches are discussed. Individually, they all have strengths and weaknesses, which led to the development of a three-component model (**Fig. 4**) that tries to balance out negative effects. First, it is important to concentrate on challenges that society faces. Once these have been identified, it becomes possible to use databases and statistics to determine which research approaches would likely have a large impact on solving the given problem. As a third component the model includes a peer-review step during which experts assess research proposals on a personal basis by visiting scientists and discussing their ideas with them.

The second question deals with the improvement of science impact on society. It has been proven that sharing advice and expertise enhances productivity. This suggests that "helpfulness" and strong communication skills could one day become one aspect during the science evaluation process (7). Instead of creating an overview of all little aspects that might help scientists to solve society's problems, this work introduced the "**friction surface**" concept. This term describes the interaction between science disciplines itself and society as whole. A large friction surface can especially be achieved by enhanced **science communication**. Three recent ways are discussed here: First, to value all scientific products and not only standard publications, secondly to create direct interaction with society by researchers (**Tab. 3**), and as a third aspects to promote student networking that starts at early stages and helps students to learn how to communicate their knowledge to non-scientists. Concerning a direct measure that universities can take to improve their interaction with society, also the use of **social media** is discussed. The tool *Altmetrics.com* enabled an analysis on how different scientific disciplines are represented in modern media types (**Fig. 5**). Universities could use this tool to actively monitor their science communication. Researchers also need to be motivated to especially write blogs and contact news websites instead of only using Facebook or Twitter, because these latter two media forms only have a very limited effect on sustainable science communication. Universities should also intensify the communication of scientific results the humanities and social sciences have obtained and sharpen their research profile in these areas (**Fig. 5**).

Convincing "outsiders" of the use of science projects is a first step in building the "magic triangle" between companies, society, and academia. The emerging questions that society has to face (23) can only become solved by smart scientists. Science has a lot of potential if communication is applied in an efficient way. An interesting example is the physics research institute CERN located in Geneva, Switzerland. CERN has done a tremendous job over the past years to promote its research and make it attractive for the general public and a large number of investors as well (40). Even though theoretical particle physics is a research discipline that is commonly assumed to be far away from the everyday life of most people, many companies do business with CERN and media coverage has been on a high level for several years now.

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