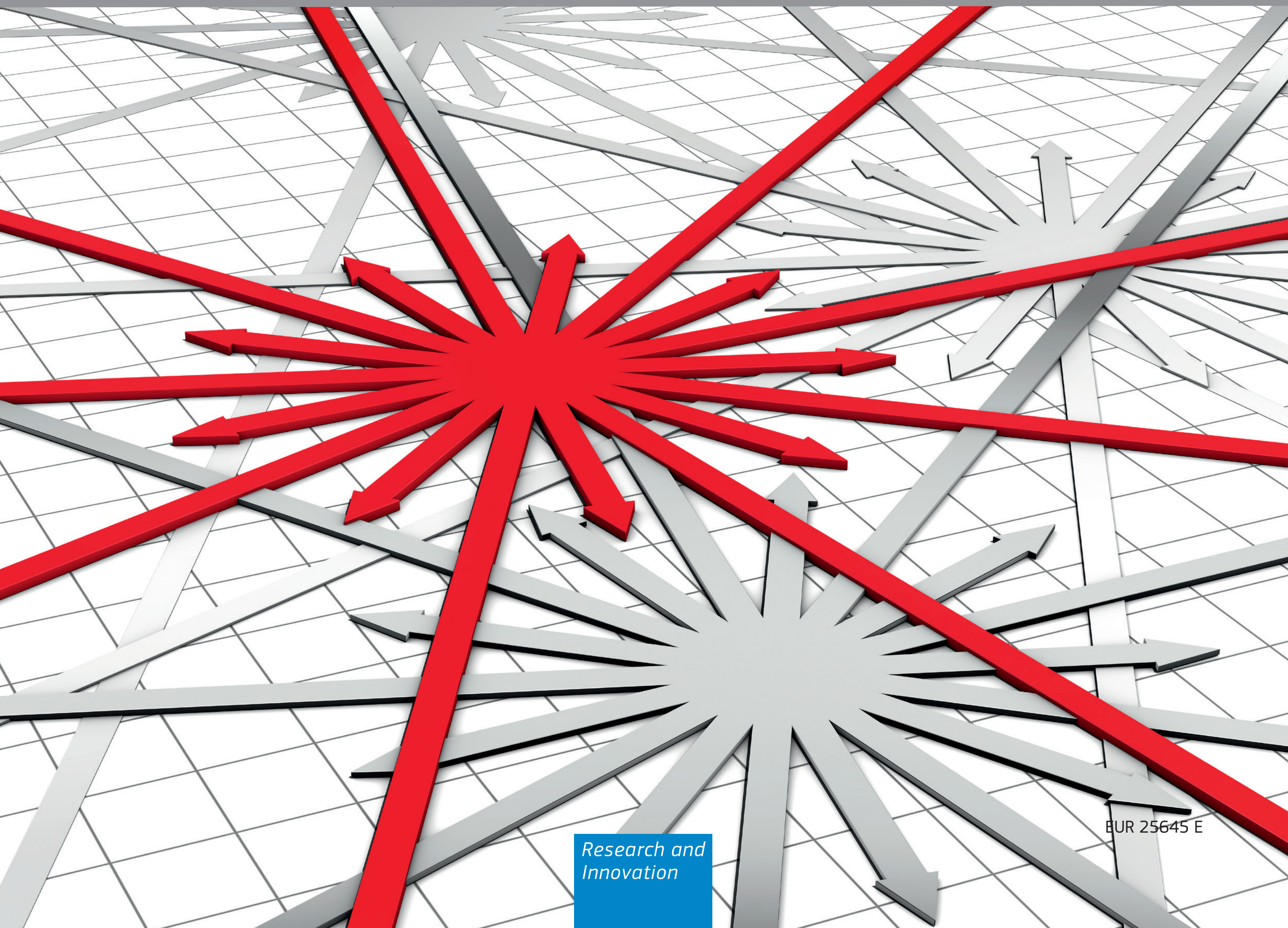
European Commission

Nanometrics

A Technometric and Socio-Economic Analysis System to Support the Development of the European Nanotechnology Strategy Options

Part II: Case Studies



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NANOMETRICS

A Technometric and Socio-Economic Analysis System to Support the Development of European Nanotechnology Strategy Options

Part II: Case Studies

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Directorate-General for Research and Innovation
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1. INTRODUCTION

1.1 Monitoring system for the assessment of nanosciences and technology

As a part of the NANOMETRICS –project a monitoring system for assessing the development of nanosciences and technology (NST) has been produced. The proposed monitoring system consists of four different areas, which are commonly used in the Science, Technology and Innovation (STI) evaluation frameworks. These include inputs, activities, outputs and outcomes/impact. In our approach the impact of NST is limited to mainly economic impact of nanotechnology research and commercialisation. The project acknowledges the methodological challenges facing the nanotechnology indicators by focusing on developing a few indicators (rather than cover a broad range whose reliability can be questioned at the outset) which are relevant and comparable across time and countries, and which are suited for continuous monitoring in real time. The monitoring system related to NST research and commercialisation is described in Figure 1 below.

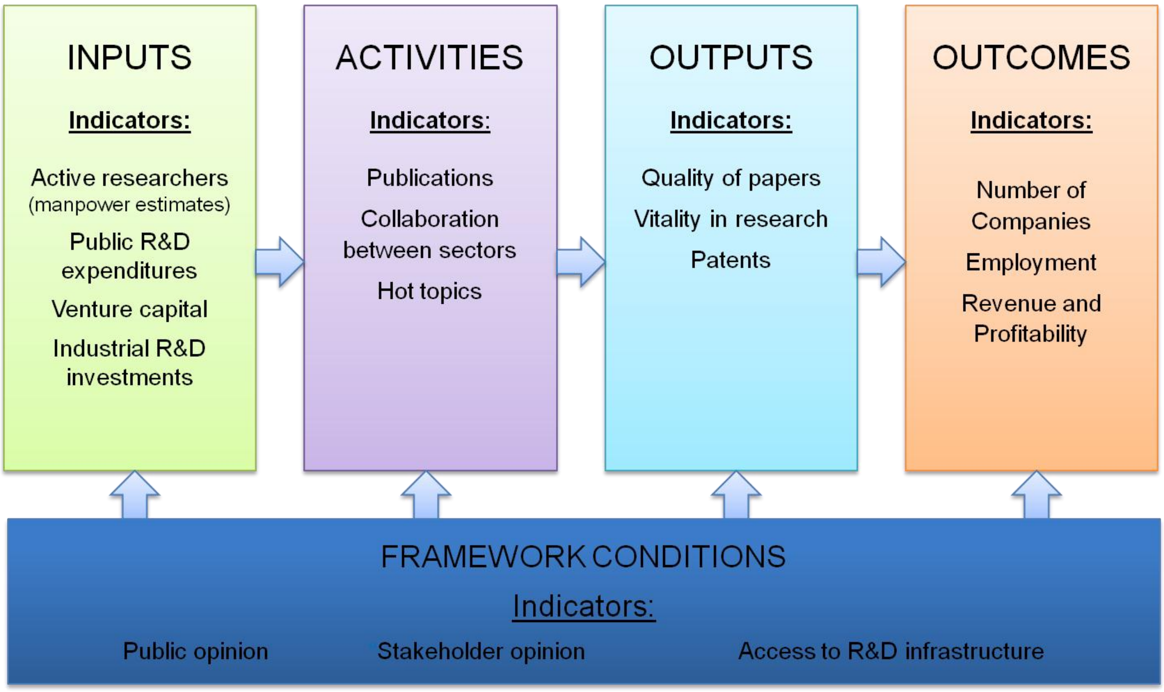

Figure 1. Description of the NST research and commercialisation monitoring system

To give examples of the indicators in use, five case studies have been carried out to assess the use of the indicator framework in selected key areas of activity. These apply the indicators to five areas in which nanotechnology is being used:

- Energy
- Environment
- Electronics
- Healthcare
- Nanomaterials

Each case study outlines the current understanding of the use of nanotechnology in each sector, provides model indicators, and finally analyses these indicators in order to both assess the strengths and limitations of the indicator and to develop conclusions about the case study area.

1.2 Sample Data and Indicators

The indicators for each case study area have been developed on the basis of sample data available to the consortium members.

The publication indicators are based on sample data derived from Web of Science 2004-2008, and 2009-2011.[1] We are focusing on 61 journals assigned to the subject category "Nanoscience & Nanotechnology". ([2]) Please note, that it is a matter of discussion to what extent the selected journals are representative for all aspects of the here chosen sectors of NST research.

An important task is to allocate each article item to the areas that we use – energy, environment, etc. The information contained in each article can be utilized for this purpose. For example, there is an abstract containing approximately 200 words, and there are references in each article that can be used for clustering the material in an appropriate manner. We use over 100 000 articles published in the about 60 nano-dedicated journals. Articles are clustered using the using the *Multi-level Aggregation Method* (MAM) -method to a hundred condensations based on common references.[3] Each such cluster is then characterized by means of noun phrases that appear in the title and abstract. The twenty most frequent terms (noun phrases) have been used for an expert to classify each cluster. In this way, our almost hundred clusters (with at least 50 articles) have been classified into the areas that we use.

Sample data has been address-harmonised, using a light hand approach, for an analysis regarding most prolific organisations active in different sectors of NST research. But, of course, the address-harmonisation has not been executed in a complete manner. Well known and obvious inconsistencies have been considered in this exercise. A harmonisation of institutional addresses covering France would be a heavy work load and we have not been able to perform such an exercise. Consequently, the sample illustrates our different indicators and cannot be said to reflect actual conditions concerning all organisations active in NST research.

The indicators used in this analysis are listed in Table 1.

Table 1. Publication indicators used in the case study report.

Indicator name	**Description (short)**
P	= Number of publications (full count).
Frac P	= Number of fractionalised publications.
SCS	= Standardized Citation Score. Relative field normalised citation score using log of citations, taking subject categories into account and measured in standard deviations.
Vitality	= Reference recency; i.e. mean age of references compared to mean age per journal sub-class(es).
Impact	$= P_{frac} * P_{f10\%}^2$ where P_{frac} is Frac P and $P_{f10\%}$ is Top 10 % (i.e. share of papers among the top 10 % most cited in the field, of the same age and article type) The number of publications is multiplied with the square of the quality proxy, in this case TOP10%, in order to give more weight to the citation indicator.

[1] The two data sets are covering the identical journals, but the assignation to areas there are small differences between the sets. This has to be considered when comparing data over time or comparing continents over time.

[2] The following 18 journals account for about 90 per cent out of the more than 100,000 articles: JOURNAL OF PHYSICAL CHEMISTRY C; NANOTECHNOLOGY; ADVANCED MATERIALS; NANO LETTERS; SCRIPTA MATERIALIA; JOURNAL OF VACUUM SCIENCE & TECHNOLOGY B; JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY; PHYSICA E-LOW-DIMENSIONAL SYSTEMS & NANOSTRUCTURES; MICROELECTRONIC ENGINEERING; MICROPOROUS AND MESOPOROUS MATERIALS; JOURNAL OF MICROMECHANICS AND MICROENGINEERING; BIOSENSORS & BIOELECTRONICS; ADVANCED FUNCTIONAL MATERIALS; MICROELECTRONICS RELIABILITY; MICROELECTRONICS JOURNAL; SMALL; LAB ON A CHIP; MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING.

[3] Blondel, V. D., Guillaume, J. L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. Journal of Statistical Mechanics: Theory and Experiment, P10008, c.f. Zhang, L., et al. Subject clustering analysis based on ISI category classification. Journal of Informetrics (2009), doi:10.1016/j.joi.2009.11.005.

The Impact indicator is an example of combinatory indicators, which in this case uses fractions of papers and a percentile indicator, in order to make it possible to rank institutions that are active in NST research. While the TOP 5%-indicator is viable at the country level, we prefer, at a lower level of granularity, i.e. for institutions like universities, institutes and companies, to use the TOP 10%-indicator. In the following analysis, there are not too few cases with numbers of articles that hardly exceed 50 papers per institution.[4]

It has to be underlined that the NST research area is highly competitive and that average values for the sample data are 0,38 for the SCS indicator and 1,11 for the Vitality indicator. Expected global averages would be 0,0 and 1,0 respectively, but as the NST-related journals are classified also as Physics and Chemistry journals, the figures are in this case somewhat higher than normally expected. NST journals are only a part of all the Chemistry and Physics journals available in the data set (Web of Science) and they are publishing the hottest papers in these subjects. We have to consider this when we judge the figures for different institutions.

The *venture capital* estimates are based on a directory of approximately 30 venture capital investments in European firms using nanotechnology over the period 2007-2011. This data was collected in the course of one partner's work on the ObservatoryNano project. The source for investment information is news reports or press releases announcing the investments. This can be considered a lower bound for the venture capital investments, as it will exclude investments that were not publicly disclosed, or investments into companies that do not identify themselves as 'nanotechnology' companies.

The *number of companies* and *employment* estimate indicators rely on raw data that was obtained from the ObservatoryNano company survey. This survey was carried out in February-March 2011, and received 100 responses from a surveyed population of approximately 1500 companies. As such this data should be considered as a snapshot rather than a truly representative sample of the nanotechnology company population.

The "*number of companies*" indicator was derived from a question requiring the respondents to state the importance to their companies of the ten sectors used in the ObservatoryNano project. Respondents who indicated that a particular sector was 'somewhat' or 'very important' are considered to be working in that sector. The data over-represents countries where the most active partners working on the survey were found (in this case Finland, and to a lesser extent Spain) accounting for the high share of Finnish companies in the sample.

The *employment* indicator was derived from a question requiring a respondent to state the overall number of employees in their company, using six size categories ranging from under 10 employees to over 1000. Respondents were then asked to estimate the proportion of their employees working with nanotechnology, using categories such as 1-25%, 26-50%, etc. The high and low employment estimates were calculated using a midpoint value for company size, and the higher and lower percentage bounds. A company with 11-50 employees who reported 51%-75% of employees working with nanotechnology would be considered having an employment level ranging from 31 x 51% to 31 x 75%.

[4] Also, this holds for the regional data presented below. For regions with less than 50 papers (Russia and Latin-South) we can probably not produce significant values.

2. ENERGY

2.1 Impact of Nanotechnology

The energy industry is likely to be affected by nanotechnology with respect to the capture, transfer and storage of energy. New and improved types of energy technologies possess the capability of addressing the grand challenges of climate change and resource efficiency. Hence the fields of science and engineering are constantly seeking to develop these new/improved types of energy technologies. Scientists and engineers have developed and still develop energy applications of nanotechnology in order to make the next leap forward from the current generation of technology. One of the most important aspects of nanotechnology is that it allows the scientists and engineers to control materials in a new way leading to an improved efficiency of products across the board.

A familiar example of nanotechnology or its implementation in practice is the LED (Light-emitting diodes), which only use about 10% of the energy of a typical incandescent or fluorescent light bulb. LEDs typically last much longer making them a viable alternative to traditional light bulbs. Batteries have also been enhanced by nanotechnology. New anodes and cathode materials have been designed that allow an increase in the amount and rate of energy that can be transferred to a battery and a significant reduction in the recharge times.[5]

A major factor in energy efficiency is thermal loss, in which energy is lost through the generation of heat. For instance the internal combustion engine loses about 64% of the energy from gasoline as heat. Any improvement in this would have a significant economic impact. However, improving the internal combustion engine in this respect usually leads to a loss in performance. Improving the efficiency of fuel cells through the use of nanotechnology appears to be more plausible by using molecularly tailored catalysts, polymer membranes, and improved fuel storage.[6]

There are still several problems related to the use of fuel cells (e.g. the storage of fuel, the expensive noble-metal catalyst needed in the process, the sensitivity of catalysts to carbon monoxide reactions etc.). Alcohols or hydrocarbons compounds are used to lower the carbon monoxide concentration in the system, adding an additional cost to the device. Nanotechnology provides a solution. Catalysts designed through nanofabrication are much more resistant to carbon monoxide reactions, thus improving the efficiency of the process. These catalysts may also be designed with cheaper materials to lower costs even more. Scientists have also solved the issue of storage by using a nanoporous styrene material (which is a relatively inexpensive material) that when super-cooled to around -196ºC, naturally holds on to hydrogen atoms and when heated again releases the hydrogen for use. [7]

2.2 Indicators-based examples

The venture capital data tracked only a single investment into companies using nanotechnology for energy applications. This was an investment of EUR 1.6 million (15 million SEK) into the Swedish firm SolVoltaics AB in 2008. In itself this would be an indication that the energy nanotechnologies are not generating investor interest, perhaps because of high-scale up costs affecting perceived return on investment. However, given the generally high level of investor interest in energy technologies, this is more likely to be a labelling issue; a firm developing novel photovoltaics is more likely to describe itself as a 'solar' company rather than a 'nanotechnology' company, despite nanotechnology being the enabling technology.

Nanotechnology research production output in the sector is measured by the number of scientific articles. The figure below shows the development in the number of publications in the major regions between 2004 and 2011. The figure indicates a strengthening in the position of Asia relative to the US-Canada and the EU, which may come as a result of increased research

[5] http://peswiki.com/index.php/Directory:Nanotechnology
[6] http://en.wikipedia.org/wiki/Energy_applications_of_nanotechnology
[7] http://en.wikipedia.org/wiki/Energy_applications_of_nanotechnology

funding in these areas. This would seem to be a trend starting in 2007, with very even development between the three regions until that point.

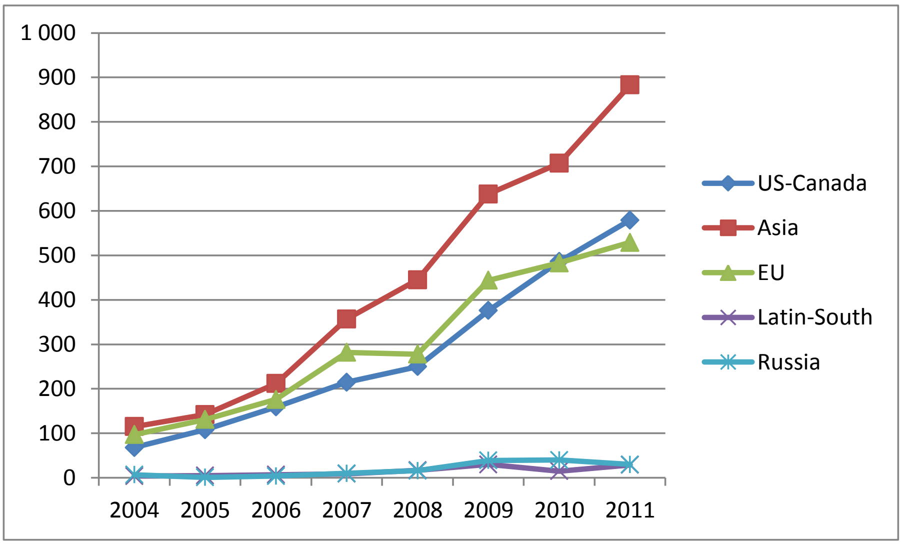

Figure 2. Number of papers (P) per World region during 2004-2011.

Another way to measure sectoral publishing activity is to use fractional counts. This indicator gives a figure of weight for the contribution of the group to the quantitative indicators of all their papers and is a way of controlling the effect of collaboration when measuring output and impact. The figure below shows the development in the number of fractionalised publications in the major regions between 2004 and 2011, and do not indicate a major difference from the previous figure, with a continued indication of recent Asian improvement in research productivity.

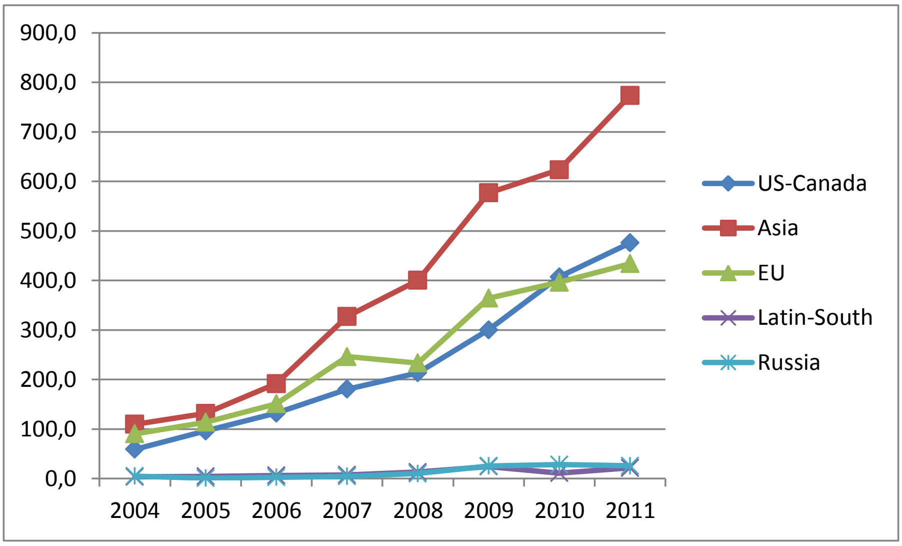

Figure 3. Number of fractionalized papers (Frac P) per World region in 2004-2011.

Citations are a way to measure the quality of research. They provide a reasonable estimate of the importance and impact of nanotechnology research accomplishments. The figure below shows the development in the quality of research by using the standardised citation score (SCS) in the major regions between 2004 and 2011. This figure shows that whilst the number of publications from Asia has increased, the citation counts for those papers are lower than US-Canada and EU equivalents. This suggests that Asian researchers may have prioritised quantity research over its quality. The unusual results from the Latin American data are more likely to be caused by the low number of publications from those regions in the sample. Also, we have to take some of the features of the SCS indicator into account; the indicator measures in standard deviations from the mean and as the citation window becomes shorter the probability that we will find citation distributions with a strong deviation from the mean becomes lower. Accordingly, it is slightly harder to receive a high SCS-score in 2009 and 2010.

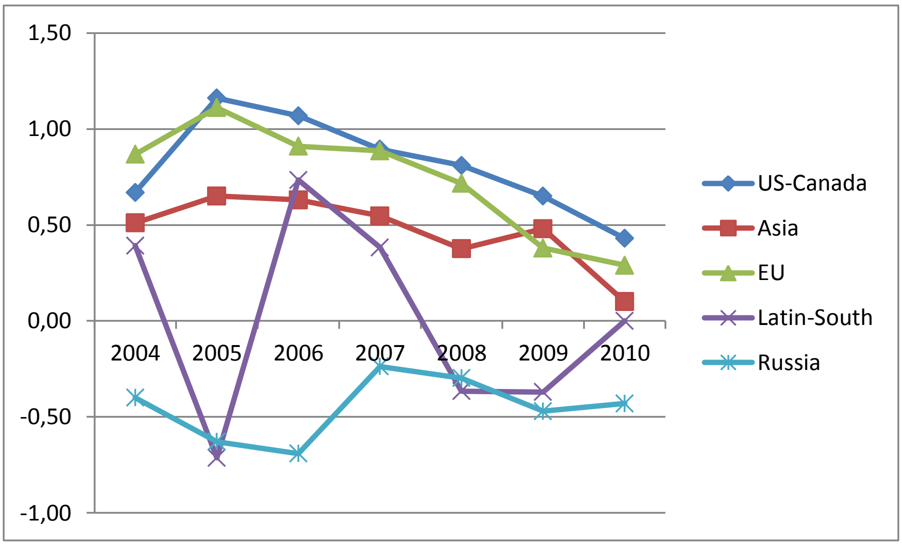

Figure 4. Standardized Citation Score (SCS) per World region during the period 2004-2010.

Another indicator measuring the quality of research is the share of papers in the top 5% of cited papers. This indicator aims specifically to reveal top level research activity. The figure below shows the development in the quality of research by using the Top 5% indicator in the major regions between 2004 and 2010. This supports the 'quantity over quality' argument for Asian research, and also suggests that the US-Canada and the EU have a remarkably even position in 2007-2008 in terms of their contributions to top level research (following a period in 2005-2006 where the US-Canada had a clear lead in their share of the most highly cited papers).

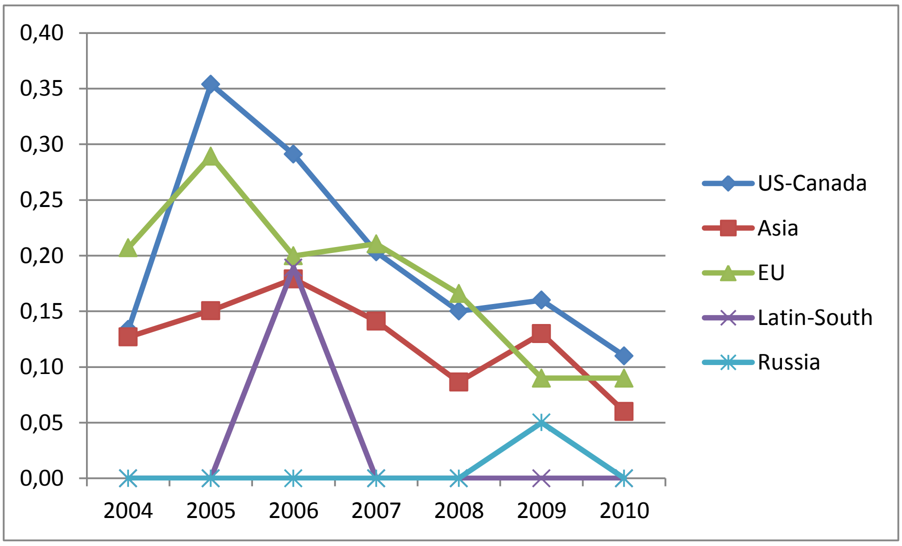

Figure 5. Share of papers in TOP5% per World region during the period 2004-2010

The "vitality" of research article references is measured as the average age of all cited references from the papers. Vitality indicates researcher's willingness to attack new problems with new measures and therefore acts as an estimate for diversity and dynamics within the research and innovation system. The figure below shows the development in the vitality of research in the major regions between 2004 and 2010. US-Canada and the EU have high levels - 20% above world average in these sub-fields - which indicates that the nano energy sector is providing research that changes the research fronts, and produces innovative research.

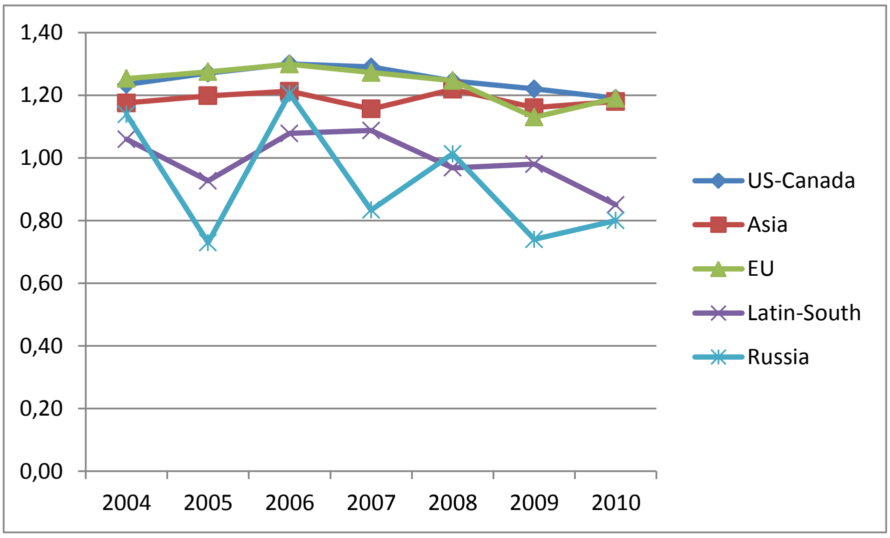

Figure 6. Reference recency (VITALITY) per World region during the period 2004-2010.

To understand which institutions are the major players within nano related energy research, two indicators are combined - fractionalised publications per organisation and TOP 10%. In Table 2 this indicator is called "IMPACT" (this indicator is explained in Table 1). This combinatory indicator makes possible to rank the different institutions active in the area of energy as this indicator concerns the number of publications and impact on the academic community. Table 2 also displays citation impact measured with the SCS indicator and vitality, measured as reference recency (VITALITY). Some of the best performing institutions – defined as those achieving high rankings from a smaller number of publications – are highlighted in bold. European institutions are marked with a frame (See Table 2).

Table 2. High IMPACT institutions plus performance indicators in Nano Energy research 2004-2008.

Organisation Energy	P	Frac P	SCS	VITALITY	IMPACT
CHINESE ACADEMY OF SCIENCES	179	136,5	0,89	1,28	21,7
MAX PLANCK GESELLSCHAFT	87	47,8	1,44	1,33	11,8
WASHINGTON UNIVERSITY	27	18,9	1,66	1,41	11,0
CAMBRIDGE UNIVERSITY	67	35,6	1,33	1,38	11,0
EINDHOVEN UNIVERSITY TECHNOL	36	15,8	2,07	1,47	10,8
NATL UNIVERSITY SINGAPORE	40	30,0	1,31	1,36	9,4
CALIFORNIA BERKELEY UNIVERSITY	36	21,7	1,39	1,40	8,8
CALIFORNIA LOS ANGELES UNIVERSITY	27	19,2	1,76	1,44	8,7
IMPERIAL COLL	24	14,4	1,90	1,43	7,9
GRONINGEN UNIVERSITY	19	9,9	2,34	1,45	7,7
CORNELL UNIVERSITY	21	13,9	1,75	1,46	7,0
UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA	51	40,3	0,98	1,18	7,0
CALIFORNIA SANTA BARBARA UNIVERSITY	27	18,3	1,82	1,33	6,9
US NATIONAL RENEWABLE ENERGY LAB	10	6,4	2,03	1,58	6,4
STANFORD UNIVERSITY	34	19,5	1,16	1,41	6,3
LINKOPING UNIVERSITY (SWE)	19	11,4	1,60	1,46	5,3
GEORGIA INSTITUTE OF TECHNOLOGY	38	28,6	1,10	1,49	5,2
KONARKA AUSTRIA	11	5,2	2,65	1,41	5,2

Energy research is an area where European institutions have excellent performances. That is made visible by the unusually high SCS-figures for organisations like Eindhoven, Groningen and Konarka. While few Asian institutions are on the list the US and EU countries share the top positions. Europe stands for one third of institutions at the list and several of them 'punch above their weight' in the ranking as they have fewer publications but higher impact.

The "*number of companies*" indicator gives an impression of the number of companies working with nanotechnology for energy applications, and their geographical distribution. Companies are evenly spread amongst major European countries, a fact that reflects broad interest in the energy sector and a lack of regional specialisation, at least at this level of detail.

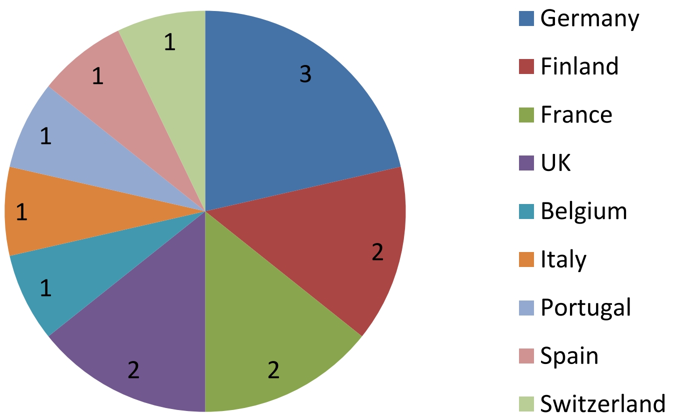

Figure 7. Number of companies who self-identify in energy sector, by country.

The "*number of employees*" indicator gives the lower and upper estimates for employment in this sector (amongst the respondents to the survey). The high variation between the maximum and minimum estimates precludes drawing strong conclusions from this data.

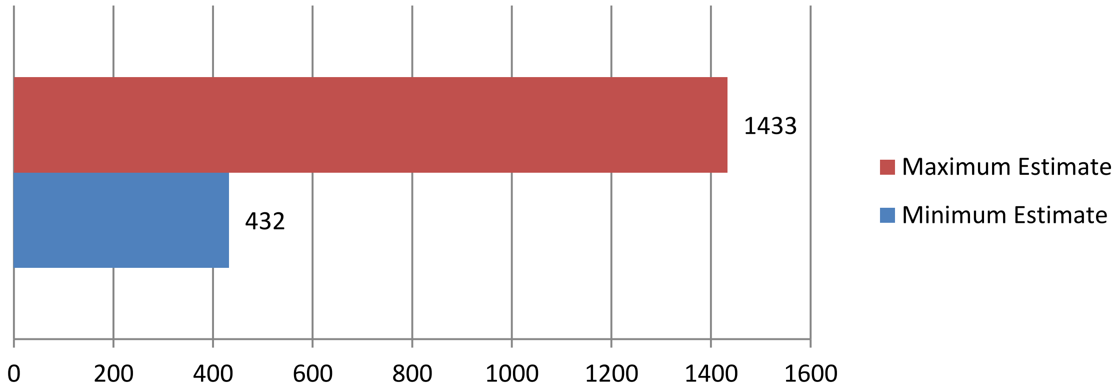

Figure 8. Estimated number of employees in this sector (min and max)

3. ENVIRONMENT

3.1 Impact of Nanotechnology

Environment applications are an important focus area for nanotechnology research and commercialisation. Nanotechnology-based solutions have shown many promising benefits, for example better pollution sensors and clean up systems, cheap and portable water treatment and more effective filters for pollution and viruses.([8]) As with nanotechnology in general, environmental applications overlap many sectors. For example, environmentally friendly fuels and lighter vehicles, etc. will be seen in the energy and transportation sectors but can also be considered as environmental applications.

One potential application of nanotechnology is in pollution remediation. Filters and processes which use nanotechnology may collect pollutants. This kind of technology may be used in water cleanup, and filters that absorb viruses and pollutants from the atmosphere. Fuel efficiency and emission reduction is also an important application field. Stronger and lighter materials created by nanotechnology also have positive impacts on the environment, for example in making goods more durable to reduce the amount of material in landfills and recycling. Environmental toxicology is an important area of research to establish whether nanoparticles may have a harmful effect if allowed in significant quantities into the environment.[9]

One of the most promising future environment and energy applications is the development of fuel cells for many uses. Photovoltaics are a nanotechnology area where commercial breakthroughs are expected to occur with the development of cheap, efficient, lightweight and flexible solar cells. Biomimicry is also one key area for nanotechnology's environmental applications. The goal is to copy plants' photosynthesis mechanism. The conversion of sunlight to hydrogen would bring together photovoltaics and biomimicry; better use of renewable energy sources along with development of fuel cells could take us to a viable hydrogen economy where we are no longer reliant on fossil fuels.([10])

3.2 Indicators-based examples

The venture capital data set did not track any investments into companies that develop environmental nanotechnologies. This suggests either that these firms are considered to be found in other sectors (such as biofuels in energy) or that they are not sufficiently attractive for investors.

Nanotechnology research production output in the sector is measured by the number of scientific articles. The figure below shows the development in the number of publications in the major regions between 2004 and 2011. This shows a dramatic surge in publications from Asia in the latter years of the sample – to an even greater extent than in the energy sector – with an evenly matched position for US-Canada and Europe. This is an indication of greater resources being put into environmental nanotechnology research in Asia and a global increase in the volume of activity (although part of the increase is accounted for by increasing indexing of research publications, meaning that more journals are added to the sample each year, but not after 2007/2008).

[8] http://www.nanoandme.org/nano-products/environment/
[9] http://www.nanoandme.org/nano-products/environment/
[10] http://www.azonano.com/article.aspx?ArticleID=1058

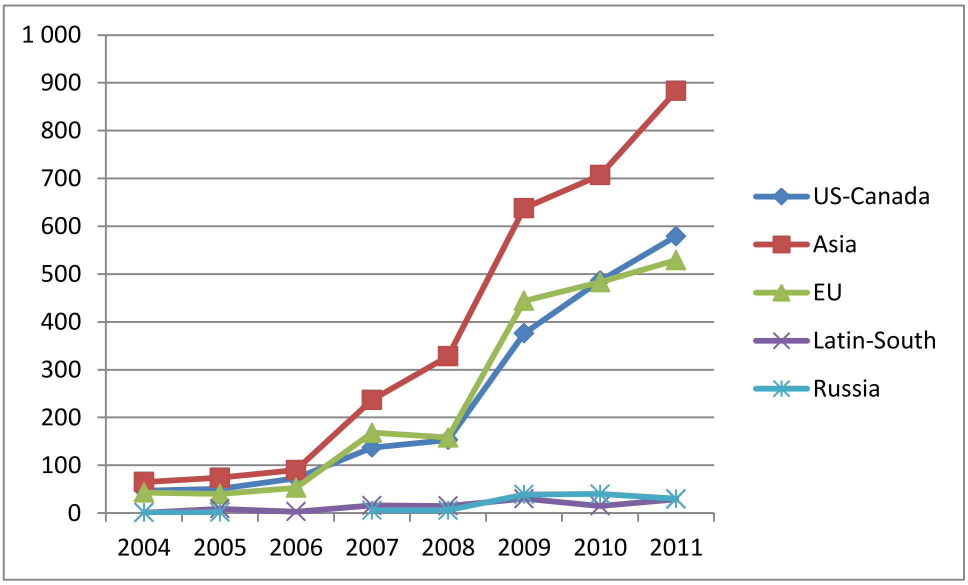

Figure 9: Number of papers (P) per World region during 2004-2011

Another way to measure sectoral publishing activity is to use fractional counts. This indicator gives a figure of weight for the contribution of the group (of nations) to the quantitative indicators of all their papers and is a way of controlling the effect of collaboration when measuring output and impact. The figure above shows the development in the number of fractionalised publications in the major regions between 2004 and 2011. As the database (Web of Science) is growing, especially during the years from 2006 to 2007, and a number of new journals are included to the indexing procedures, the figures are somewhat inflated. But, in relative terms we find that the Asian increase is very fast and that EU and US-Canada is losing ground. Russia and South America have still just entered into the field of nano research.

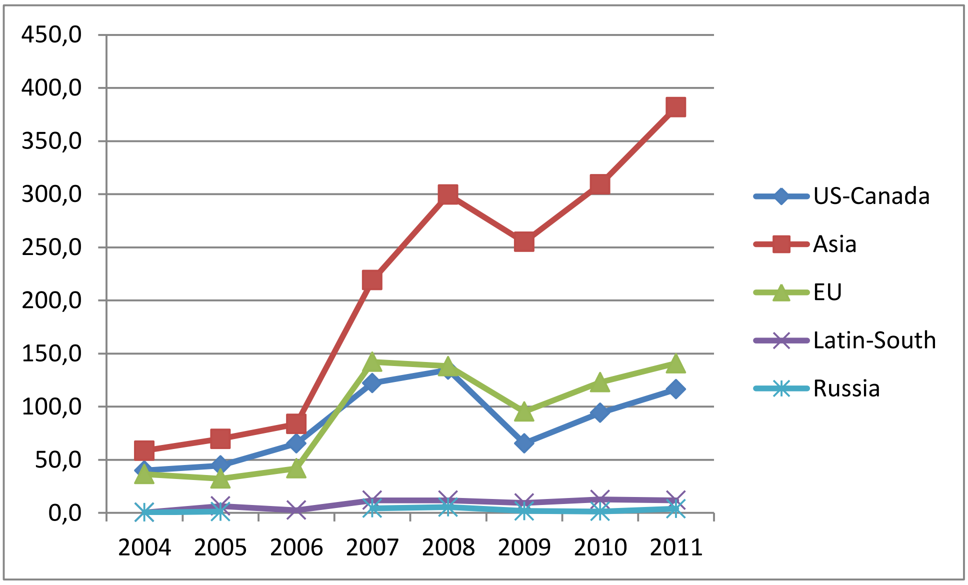

Figure 10. Number of fractionalized papers (Frac P) during 2004-2011.

Relative citation scores are a way to measure the quality of research. It provides a reasonable estimate of the importance and impact of nanotechnology research accomplishments. The figure below shows the development in the quality of research by using the standardised citation score (SCS) in the major regions between 2004 and 2010. Here the quality difference between Asian and US-Canada and EU research is less pronounced than in the energy sector, which suggests that rather than quantity over quality, Asian researchers are producing more work of an equivalent quality to that of their counterparts in US-Canada and Europe.

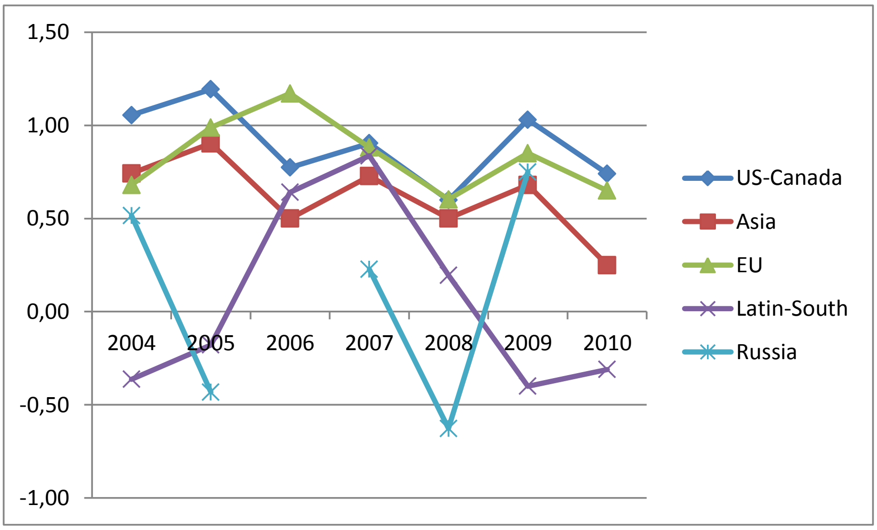

Figure 11. Standardized Citation Score (SCS) per World region during the period 2004-2010.

Another indicator measuring the quality of research is the share of papers in the top 5% of cited papers. This indicator aims specifically to reveal top level research activity. The figure below shows the development in the quality of research by using the Top 5% indicator in the major regions between 2004 and 2010. This supports the earlier analysis; after a year (2005) in which over a third of the top 5% papers were produced in the US-Canada, representation of the three major regions in this elite group is very even. The data also suggests that more high quality work is being carried out in Latin and South America – perhaps because of greater local needs for environmental nanotechnologies.

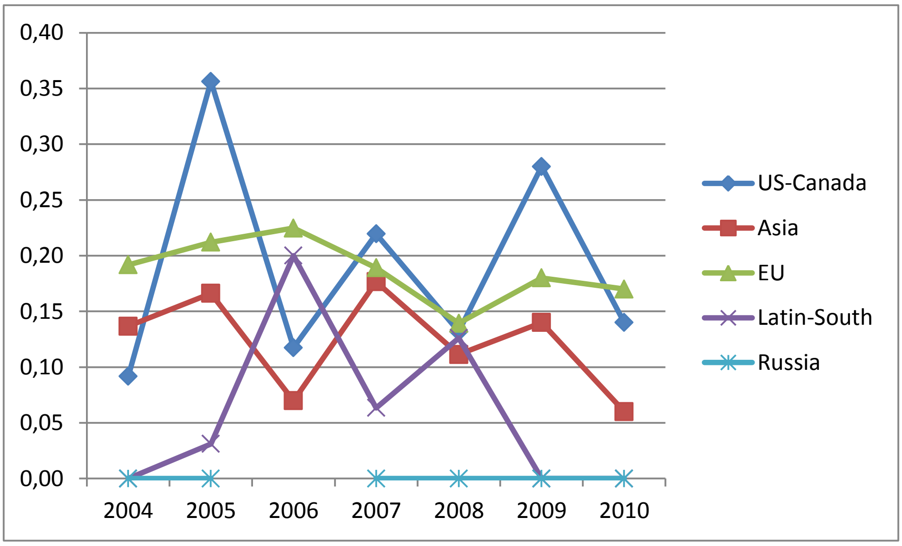

Figure 12. Share of papers in TOP5% per World region during the period 2004-2010

The "vitality" of research article references is measured as the average age of all cited references from the papers. This Vitality indicates researcher's willingness to use the most recent research as a basis for their findings. The figure below shows the development in the vitality of research in the major regions between 2004 and 2010. Despite some variations in the early part of the last decade, this data now suggests that global research is equal in terms of its closeness to the research front, with no region notably ahead of or trailing the others.

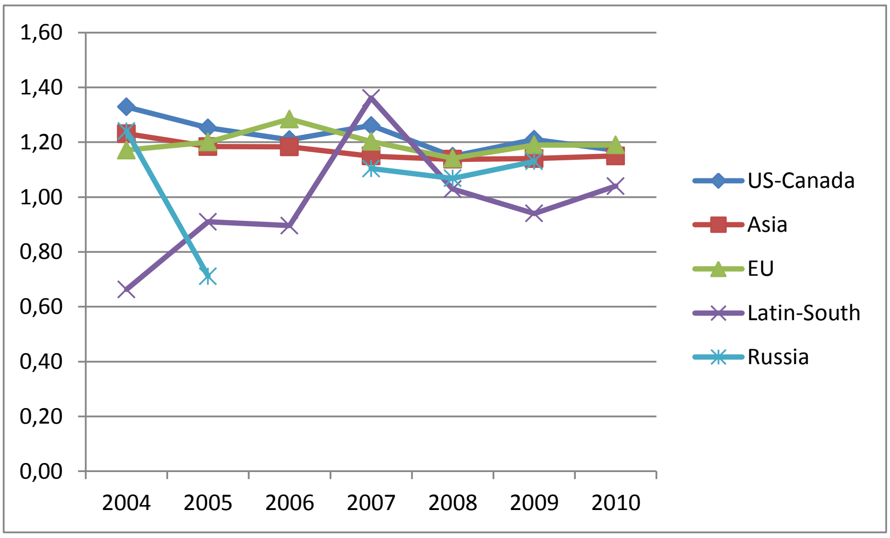

Figure 13. Reference recency (VITALITY) per World region during the period 2004-2010.

Using our methodology for "IMPACT" we display in Table 14 (below) the major players within environmentally related NST research. Erlangen Nürnberg University is at the top of the list and is a dominant player together with EPFL and the Swiss Federal Research Institute. Displayed on the top list are 12 organisations only as environmental research is very much dispersed over many organisations and few have an impact from many publications and citations. While US have only three institutions on the list, Chinese and South Korean institution are more represented, which mirrors the graph above showing number of papers per region. Figures for relative citation impact (SCS) and Vitality are in all cases in the order of what would be expected from world leading institutions.

Table 14. High IMPACT institutions plus performance indicators in Nano Environment research 2004-2008.

Organisation Environment	P	Frac P	SCS	VITALITY	IMPACT
PENN STATE UNIVERSITY	32	24,2	2,13	1,64	14,5
CHINESE ACADEMY OF SCIENCES	92	66,4	1,02	1,20	10,5
ERLANGEN NURNBERG UNIVERSITY	19	12,8	1,90	1,45	9,4
ECOLE POLYTECH FEDERALE LAUSANNE	21	13,0	1,54	1,42	6,5
SWISS FEDERAL INSTITUTE OF TECHNOLOGY	18	8,3	1,80	1,44	6,2
WASHINGTON UNIVERSITY	11	7,6	1,66	1,50	4,3
MAX PLANCK GESELLSCHAFT	46	22,5	1,01	1,19	3,9
SEOUL NATL UNIVERSITY	12	6,4	1,67	1,32	3,7
DALIAN UNIVERSITY TECHNOL	9	6,2	1,57	1,49	3,5
WUHAN UNIVERSITY TECHNOL	8	6,3	1,52	1,32	3,2
NORTHWESTERN UNIVERSITY	10	7,5	1,43	1,42	3,1
CALIFORNIA DAVIS UNIVERSITY	5	4,0	1,65	1,07	3,1

The "number of companies" indicator gives an impression of the number of companies working with nanotechnology for energy applications, and their geographical distribution. This largely mirrors the position in energy, with companies found in eight different EU states. The largest number of companies is in Germany, but this is not a significant increase when considered on a per capita basis.

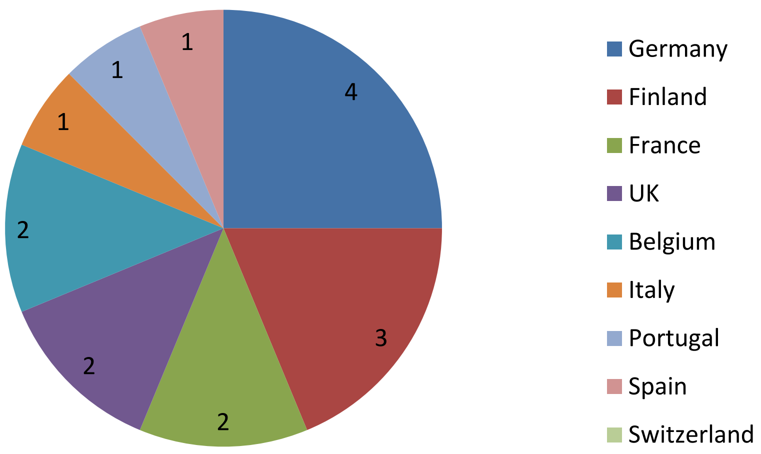

Figure 15: Number of companies who self-identify in environment sector, by country

The "number of employees" indicator gives the lower and upper estimates for employment in this sector (amongst the respondents to the survey). The average of the lower and upper estimate is slightly higher than for energy, indicating that current employment in this sector is higher.

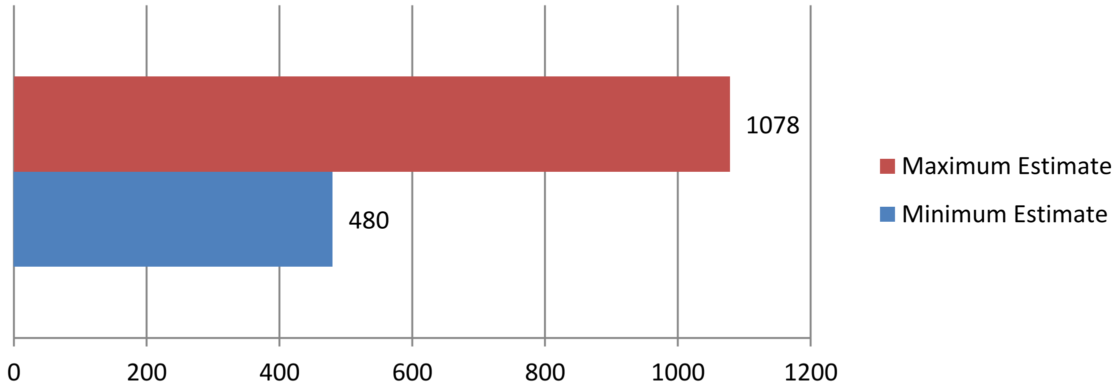

Figure 16: Estimate number of employees in this sector (min and max)

4. ELECTRONICS

4.1 Impact of Nanotechnology

The usage of nanotechnology in the electronics industry is often divided into evolutionary CMOS downscaling (typically referred to as ’More Moore’), use of nanotechnology in associated components (’More than Moore’) and novel approaches for producing logic components.

Work on the 'More Moore' domain clearly takes place at the nanoscale, with the average gate size of Intel’s newest generation of Sandy Bridge semiconductors being 32 nm. Research work in this area is globally distributed, although there are European centres of excellence around Dresden in Germany and Grenoble in France. Because of the expenses involved in designing and building semiconductor fabrication facilities (‘fabs’), much of this work would be expected to be carried out by or with corporate research laboratories, with close links between publications and patenting.

A more diverse field of activity is work in the 'More than Moore' domain. This will include the use of nanotechnology in components such as memory and displays. Active areas of research which are known to exist in Europe include the use of carbon nanomaterials as replacements for Indium Tin Oxide in transparent conductive electrodes for displays and touch screens, or using quantum dots in displays. Research work has also been carried out into alternative approaches for data storage, using techniques such as MRAM and phase-change materials. Time to market for these applications vary, but news reports indicate that display applications are already at the prototype stage.

Other approaches which one would expect the indicators to identify include the use of nanostructures to build logic components; the research work on Nanowires which is cantered around the Samuelson group at Lund University in Sweden is one example of this.

4.2 Indicators-based examples

The venture capital data set tracked EUR 61 million of investments in nano-electronics companies in Europe, across a total of eight individual deals.

Table 4. Sample of recent venture capital investments in companies developing nanotechnology applications in electronics

Company	Country	Value (€)	Investor	Date
GLO AB	Sweden	18 346 400	Provider Venture Partners, Hafslund Venture, Agder Energi Venture, Teknoinvest, VantagePoint Venture Partners. LU Innovation, LUAB	4.10.2010
Crocus Technologies	France	8 500 000	AGF Private Equity, CDC Innovation, NanoDimension, Sofinnova, and Ventech, raise EUR 8,5 m. The company was also awarded an additional EUR 3 m in funding from OSEO.	3.10.2008
Novaled AG	Germany	8 500 000	eCAPITAL, TechnoStart, KfW and TUDAG, all from Germany, as well as Credit Agricole Private Equity, TechFund and CDC Innovation from France	14.1.2009
GLO AB	Sweden	7 937 600	Teknoinvest and Nano Future Invest, Hafslund Venture AS, Agder Energi Venture AS, Provider Venture Partners, LU Innovation	3.9.2009
OptoGaN	Finland	5 000 000	Nordic Venture Fund, Via Venture Partners and previous investors VNT Management Oy / Power Fund I and Finnish Industry Investment	1.5.2007

The venture capital indicator supports the perceived readiness of applications in displays (reflected by Glo AB) and memory (Crocus Technologies), and suggests that this has been a sector which investors understand and have interest in.

Nanotechnology research production output in the sector is measured by the number of scientific articles. The figure below shows development in the number of publications in the major regions between 2004 and 2011. The first item to note is that the number of publications is much higher than for energy and environment (where the EU generated 150 and 275 publications in 2008 respectively). All three major world regions show an increase in the number of publications, though the rate of increase for Asia is greater, given that region a clear lead after the year 2007. This may be indicative of greater investment in research in these areas, although a more detailed analysis would be required to understand whether this is driven by a single country, e.g. Taiwan. Figure 18 shows fractional count and this indicator give a similar picture.

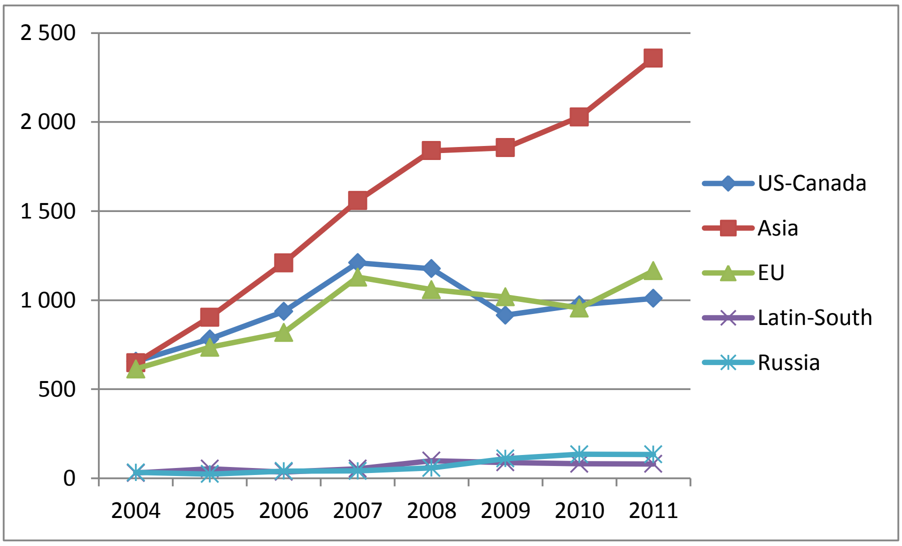

Figure 17: Number of papers (P) per World region during 2004-2011.

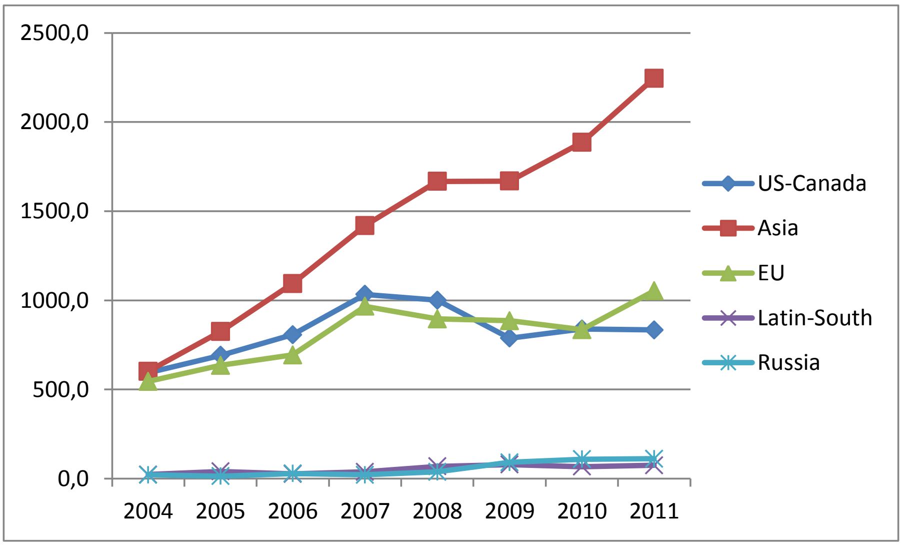

Figure 18. Number of fractionalized papers (Frac P) during 2004-2011.

Relative citation scores are a proxy for measuring the quality of research. These provide an estimate of the importance and impact of NST research accomplishments. Figure 19 below shows the development of the quality of research by using the standardised citation score (SCS) in the major regions between 2004 and 2010. For the EU region this indicator is quite stable over time, but US-Canada seems to be levelling out from a very high level at the beginning of the period. Although Asia have such a strong development in number of publications they seem to be able to uphold their citation rates, which is far from expected when a region has almost exponential growth in publications.

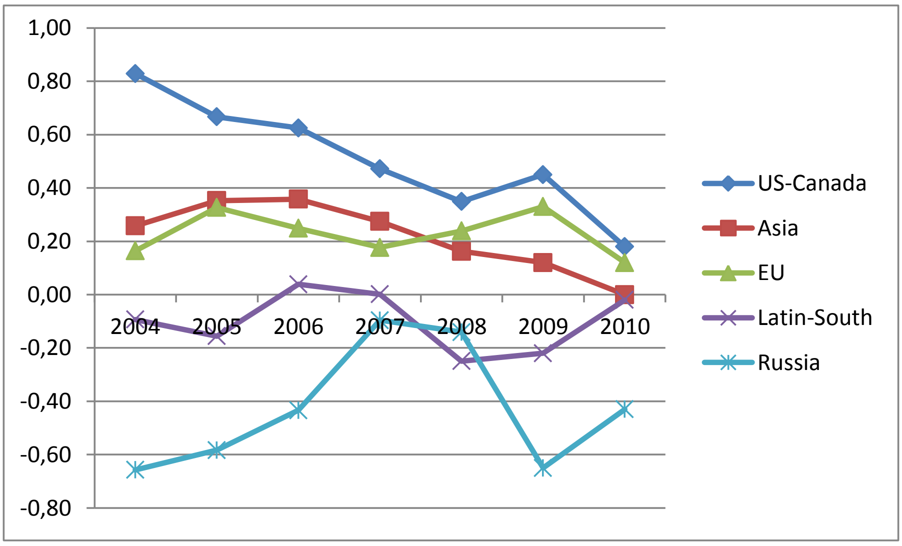

Figure 19. Standardized Citation Score (SCS) per World region during the period 2004-2010.

Another indicator measuring the quality of research is the share of papers in the top 5% of cited papers. This indicator aims specifically to reveal top level research activity. The figure below shows the development in the quality of research by using the Top 5% indicator in the major regions between 2004 and 2010. The data bears out the message from the previous indicator; US-Canada research is of a higher quality – though the quality advantage is declining – whilst Asia and the EU produce work of a similar quality.

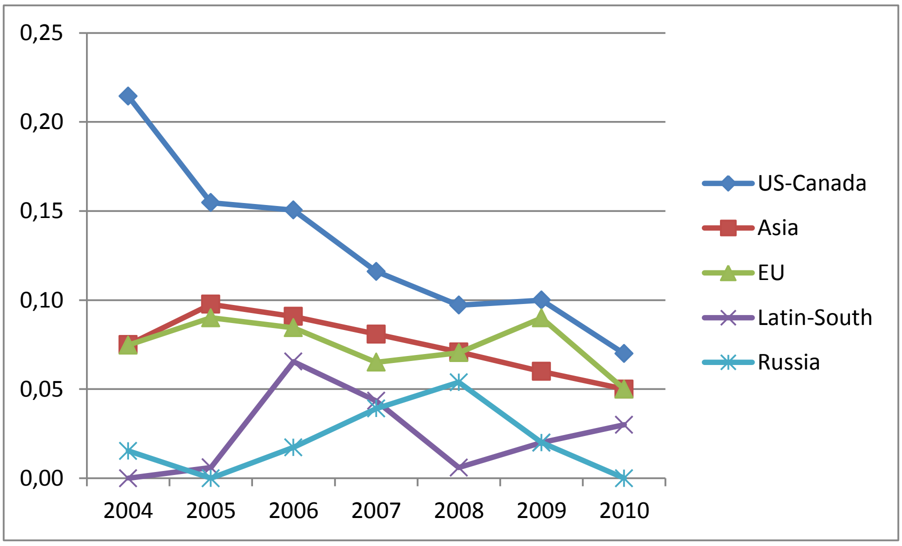

Figure 20. Share of papers in TOP5% per World region during the period 2004-2010

Vitality indicates the extent to which researchers uses the latest references for their own research. To some extent that can be a proxy for newness and dynamics within the research and innovation system. The figure below shows the development in the vitality of research in the major regions between 2004 and 2010. As with the other sectors, this indicator suggests that global research is consistently addressing recent research trends, to the same extent as with Energy.

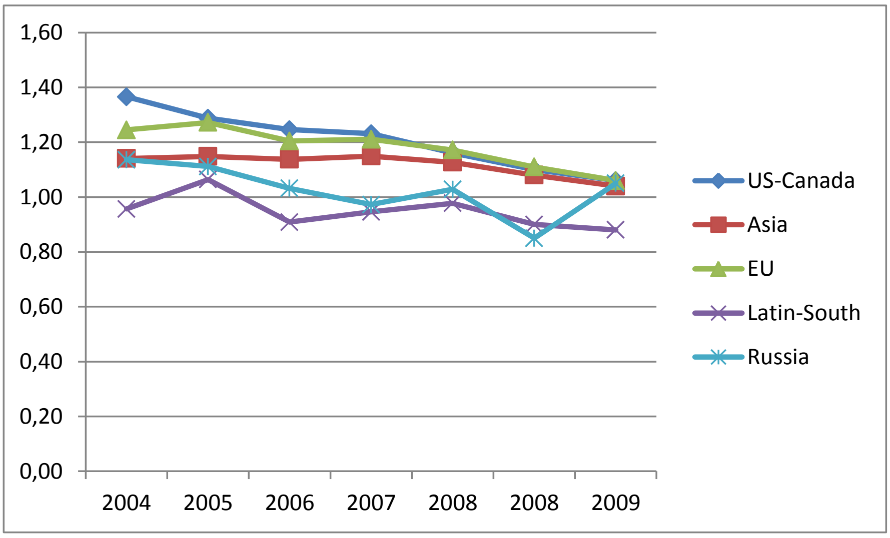

Figure 21. Reference recency (VITALITY) per World region during the period 2004-2010.

To understand which institutions are the major players within nano-related electronics research, two indicators are combined - fractionalised publications per organisation and TOP 10%. In the table below this indicator is called "IMPACT". It is therefore possible to rank the different institutions active in the area of nano-electronics as this indicator combines the number of publications and impact on the academic community. This table below also displays citation impact measured with the SCS indicator and vitality, measured as reference recency. Some of the best performing institutions – defined as those achieving high rankings from a smaller number of publications - are highlighted in bold.

Table 5. High IMPACT institutions plus performance indicators in Nano Electronics research 2004-2008.

Organisation Electronics	P	Frac P	SCS	VITALITY	IMPACT
CHINESE ACADEMY OF SCIENCES	599	393,8	0,72	1,20	38,5
GEORGIA INSTITUTE OF TECHNOLOGY	153	103,1	1,11	1,47	25,0
HARVARD UNIVERSITY	74	52,8	1,66	1,41	22,6
LUND UNIVERSITY	71	49,6	1,12	1,40	12,8
RICE UNIVERSITY	84	54,0	1,02	1,38	10,5
MAX PLANCK GESELLSCHAFT	150	70,2	0,96	1,27	9,8
MIT	132	86,2	0,93	1,32	9,5
CALIFORNIA LOS ANGELES UNIVERSITY	59	38,7	1,20	1,33	9,4
CALIFORNIA BERKELEY UNIVERSITY	160	96,4	0,86	1,30	8,9
PEKING UNIVERSITY	162	113,6	0,72	1,32	8,8
NORTHWESTERN UNIVERSITY (PRC)	85	63,1	0,99	1,33	7,9
TSING HUA UNIVERSITY	119	89,1	0,64	1,27	7,8
PENN STATE UNIVERSITY	115	78,9	0,75	1,18	7,8
STANFORD UNIVERSITY	79	52,5	1,12	1,41	7,7
WASHINGTON UNIVERSITY	69	51,5	1,04	1,26	7,6
TORONTO UNIVERSITY	60	48,2	0,97	1,37	7,5
CITY UNIVERSITY HONG KONG	89	53,5	0,88	1,20	7,0
US NATL RENEWABLE ENERGY LAB	29	18,6	1,49	1,38	6,8
CALIFORNIA SANTA BARBARA UNIVERSITY	60	38,3	1,23	1,22	6,8
MUNICH UNIVERSITY	56	29,3	1,31	1,29	6,7
MICHIGAN UNIVERSITY	79	52,6	0,70	1,24	6,6
UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA	102	83,1	0,62	1,23	5,4
CAMBRIDGE UNIVERSITY	137	80,3	0,76	1,27	5,3
CALTECH	53	39,4	0,72	1,35	5,2
SOUTH CHINA UNIVERSITY OF TECHNOLOGY	30	18,8	1,27	1,25	5,2

Using a ranking based on the Impact-indicator we can see that US institutions dominate the list with 13 of 25 at the top list. European institutions (4) are marked with a solid line and Chinese organisations (7) are highlighted with a dotted line. Europe does not seem to have a single institution with a large production although MPI (Max Planck Gesellschaft) to some extent fulfils that role, but in this case all different parts of MPI are collected under one heading. It should be underlined that this is probably also the case with the Chinese Academy of Science.
We have also tried another ranking based on Field Adjusted Production (FAP) times the Standard Citation Score (data not displayed here).([11]) Results were to a large extent identical to the IMPACT, but Europe has a smaller representation on the top list as there are many European organisations with too few papers. Figures for relative impact (SCS) and Vitality are

[11] FAP was constructed using Scandinavian reference values for the manpower estimates. SCS was counted with a +1 in order to avoid negative values.

high; SCS-figures from 0.80 and higher are pointing at performances equal to what would be expected from excellent world leading institutions.

The "number of companies" indicator gives an impression of the number of companies working with nanotechnology for energy applications, and their geographical distribution. As the venture capital data would suggest, the number of companies working with nano-electronics is higher than energy and environment, with strong positions for Germany, France, and Finland (where the combination of VTT and Nokia provides a strong nano-electronics cluster).

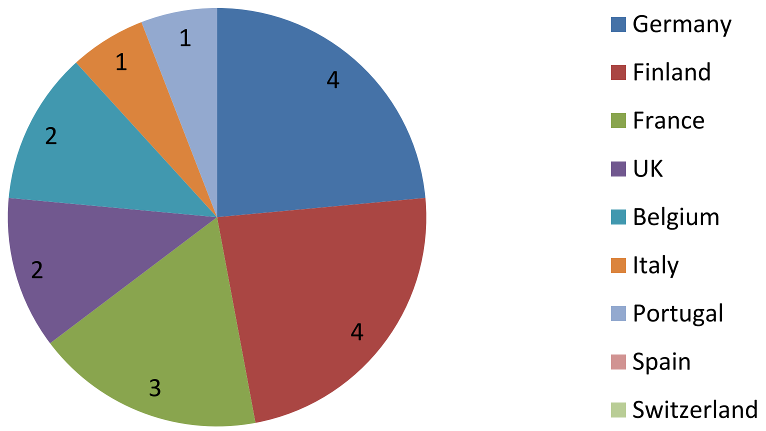

Figure 21: Number of companies who self-identify in electronics sector, by country

The distribution of companies suggests that company activity in this area is linked either to centres of excellence in this area (in France, Germany, and around IMEC in Belgium), or the presence of large electronics firms (Nokia in Finland).

The number of employees' indicator gives the lower and upper estimates for employment in this sector (amongst the respondents to the survey). The average number of employees is significantly higher compared to other sectors, providing a weak indicator of somewhat greater size (and therefore maturity) of companies in this area.

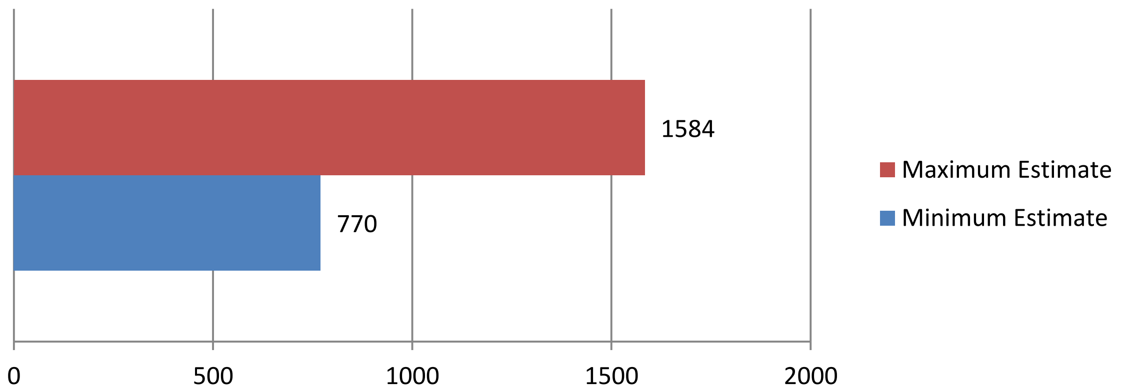

Figure 22: Estimate number of employees in this sector (min and max)

5. HEALTHCARE

5.1 Impact of Nanotechnology

Several areas of medical care already benefit from the advantages offered by nanotechnology. The first nanotechnology-based targeted drug delivery systems are already on the market, while some are in clinical trials or under development (by far the largest part). For example, coating a drug in different molecules can make it more soluble in water (for easier application), allow it to penetrate cell membranes more easily or even target it to a specific tissue or organ([12]).

New concepts for regenerative medicine create new opportunities for patients with organ failure or severe injuries, because artificial skin, bone and cartilage are in an advanced stage of development and partly already on the market. Moreover, nanotechnology enables the combination of the "active ingredient" of the drug with stabilising molecules or by new processing technologies resulting in a drug as a much finer powder. These can be taken using an inhaler and are more quickly absorbed into the body than traditional methods.[13]

Nanotechnology and especially nanomedicine is the industry of the future and it affects both health care and well-being on a large scale. Major potential benefits include improved water purification systems, physical enhancement, nanomedicine, better food production methods and nutrition. Industry has increasing interest in stepping into the area of nanomedicine and the expected market share of final products is expected to be significant. In addition to the improved quality of health care, the creation of new jobs can be expected.[14]

As discussed above, the possible mindset change from reactive to preventing i.e. being able to detect illnesses in the infant stage and being able to provide a cure instantly would change the whole health care industry. This would call for restructuring of hospitals and health care systems all over the world and the effects of this would be enormous (the current amount of hospital beds, medicine, doctors, nurses, medical devices and other related facilities would be highly over sized). This could create both positive and negative effects; municipalities tackling the increasing costs of public sector healthcare in many nations would probably benefit from it, but there may also be challenges in improving access to healthcare for all segments of the population.

There are also potential risks related to environmental, health, and safety issues; transitional effects such as displacement of traditional industries as the products of nanotechnology become dominant; military applications such as biological warfare and implants for soldiers; and surveillance through nano-sensors, which are of concern to privacy rights advocates. These may be particularly important if potential negative effects of nanoparticles are overlooked before they are released.[15]

The promising possibilities that nanomedicine might offer in the future have to be counterweighted against possible risks of this new technology. The impacts of finding a cure for cancer or HIV would bring a massive change especially in the developing and least developed countries. However, there is some concern that the claimed benefits of nanotechnology will not be evenly distributed, and that any benefits (including technical and/or economic) associated with nanotechnology will only reach affluent nations. This concern is supported by the fact that the majority of nanotechnology research and development - and patents for nanomaterials and products - is concentrated in developed countries (e.g. the United States, Japan, Germany, Canada and France). In addition, most patents related to nanotechnology are concentrated amongst few multinational corporations, such as IBM, Advanced Micro Devices and Intel, who are not directly much related to Healthcare field.

[12] http://www.nanoforum.org/educationtree/healthcare/healthcare-newdelivery.htm
[13] http://www.nanoforum.org/educationtree/healthcare/healthcare-newdrugs.htm
[14] http://www.etp-nanomedicine.eu/public/about/objectives-mission
[15] http://en.wikipedia.org/wiki/Impact_of_nanotechnology#cite_note-2

5.2 Indicators-based examples

The venture capital data set tracked EUR 74 million of investments in nanomedicine companies in Europe, across a total of five individual deals. The five largest deals are shown below. This sample is dominated by a single company, Oxford Nanopore, which has received investments totally just under EUR 70 million. This is an indication that companies that succeed in this sector will gain access to high growth high volume markets which are particularly interesting to venture capital investments – although this concentration could starve other firms of funding.

Table 6. Sample of recent venture capital investments in companies developing nanotechnologies for healthcare

Company	Country	Value (€)	Investor	Date
Oxford Nanopore	UK	28 313 500	Lansdowne Partners, IP Group, Invesco Perpetual, Redmile Group, Illumina and other undisclosed investors	26.4.2011
Oxford Nanopore	UK	19 955 538	Illumina UK, Lansdowne Partners and Invesco Perpetual, alongside new undisclosed US institutional investors	2.2.2010
Oxford Nanopore	UK	15 743 140	Illumina	12.1.2009
Genomic Vision	France	4 000 000	Vesalius BioCapital, Societe Generale Asset Management Alternative Investments (SGAM AI)	24.7.2008
Oxford Nanopore	UK	2 586 373	Private investor	12.1.2009

Nanotechnology research production output in the sector is measured by the number of scientific articles. The figure below shows the development in the number of publications in the major regions between 2004 and 2011. The amount of research work in this area is greater than Energy or Environment, but around half the level of nano-electronics. Nanomedicine is the first area in this review in which Asia is not producing the clearly largest share of publications. Increases in this area are consistent, with Europe losing its equal position only in the later period.

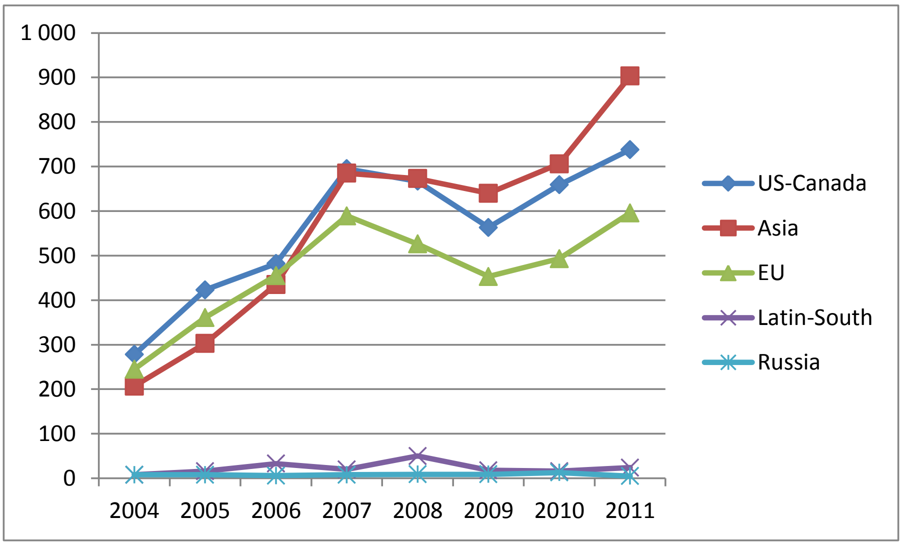

Figure 23: Number of papers (P) per World region during 2004-2011.

Another way to measure sectoral publishing activity is to use fractional counts. This indicator gives a figure of weight for the contribution of the group to the quantitative indicators of all their papers and is a way of controlling the effect of collaboration when measuring output and impact. The figure below shows the development in the number of fractionalised publications in the major regions between 2004 and 2011. The fractional count paints Europe in better light, suggesting that European researchers are more involved in these papers than the previous indicator suggests.

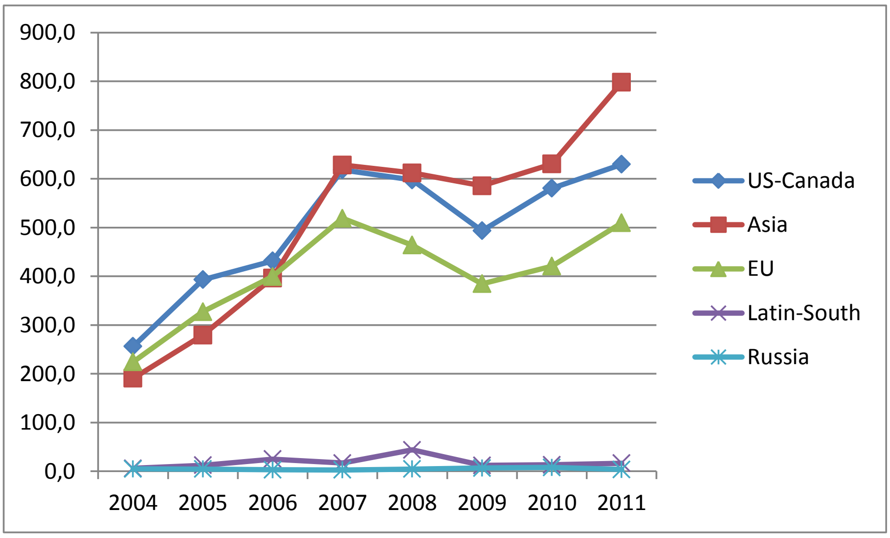

Figure 24. Number of fractionalized papers (Frac P) during 2004-2011.

Relative citations can, according to many, measure the quality of research. It provides a reasonable estimate of the importance and impact of nanotechnology research accomplishments. The figure below shows the development in the quality of research by using the standardized citation score (SCS) in the major regions between 2004 and 2010. The SCS declines as the number of publications – and therefore the number of possible citations – increases, although this decrease is consistent across major regions, and is not indicative of any country specific changes in quality. Russia and Latin-South have few papers (<20) and changes in the citation indicators (e.g. sudden peaks) are therefore of no significance.

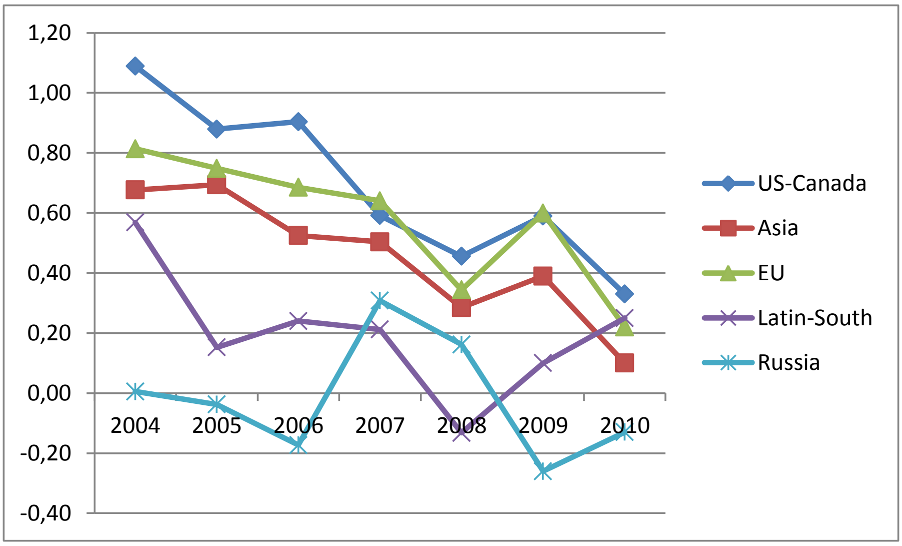

Figure 25. Standardized Citation Score (SCS) per World region during the period 2004-2010.

Another indicator measuring the quality of research is the share of papers in the top 5% of cited papers. This indicator aims specifically to reveal top level research activity. The figure below shows the development in the quality of research by using the Top 5% indicator in the major regions between 2004 and 2010. This data suggests that the US did have a better position in the most highly cited papers than the SCS would suggest, but that this has declined.

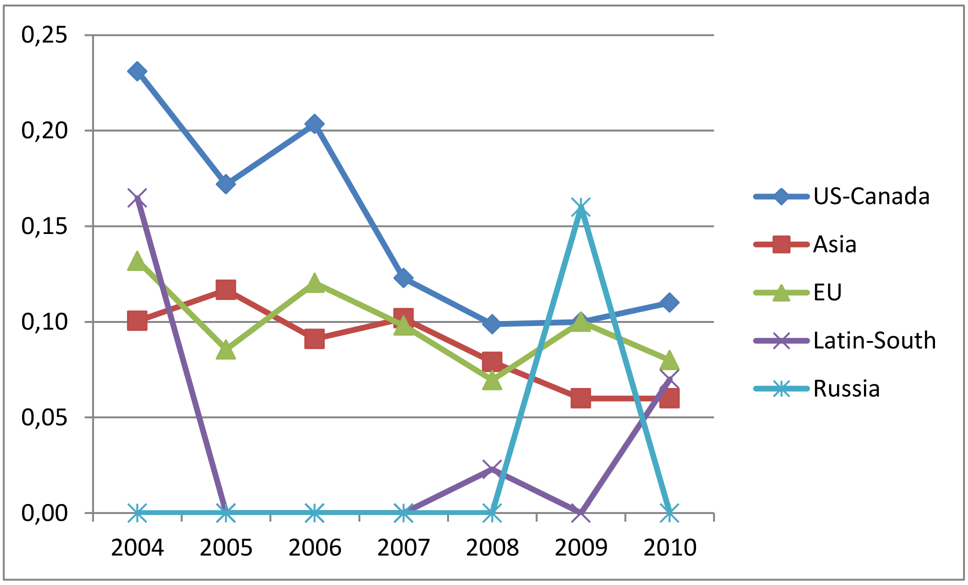

Figure 26. Share of papers in TOP5% per World region during the period 2004-2010.

The Vitality of research article references is measured as the average age of all cited references from the papers. This Vitality indicates researcher's willingness to attack new problems with new measures and therefore acts as an estimate for diversity and dynamics within the research and innovation system. The figure below shows the development in the vitality of research) in the major regions between 2004 and 2010.

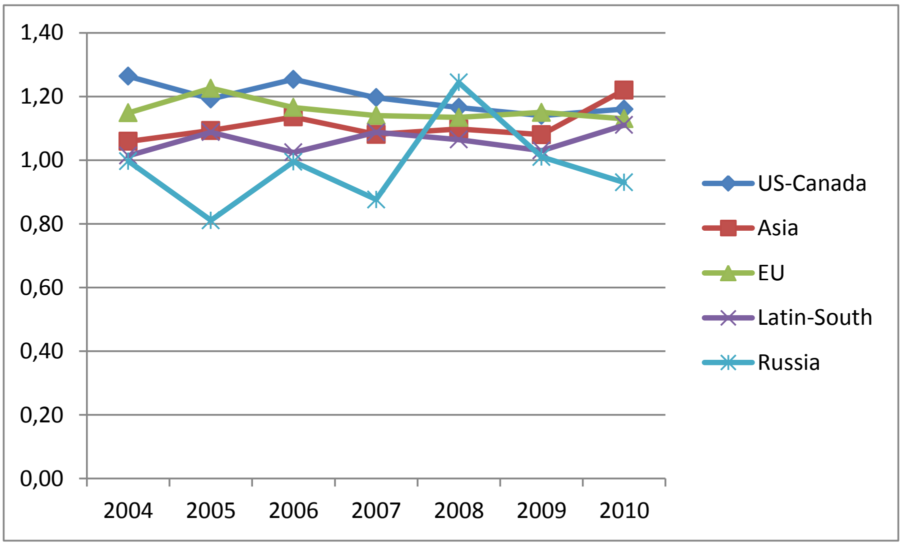

Figure 27. Reference recency (VITALITY) per World region during the period 2004-2010.

The following ranking of academic institutions is based on the methodology described in the previous chapter. Activities within the nano healthcare field are distributed among many organisations. Performances over the period are rather promising (see the SCS indicator) and it is therefore a memento that European organisations are only represented with two organisations at the list of top twenty. Actually, if we expand the list to 200 organisations we would still find that European organisations are underrepresented.

Table 7. High IMPACT institutions plus performance indicators in Nano Health Care research 2004-2008.

Organisation Health	P	Frac P	SCS	VITALITY	IMPACT
MIT	124	78,3	1,37	1,33	26,9
HARVARD UNIVERSITY	96	50,8	1,54	1,35	20,9
CHINESE ACADEMY OF SCIENCES	172	132,1	0,84	1,13	17,2
NANJING UNIVERSITY	62	47,4	1,10	1,10	9,7
MICHIGAN UNIVERSITY	102	88,1	0,81	1,27	9,5
CALIFORNIA IRVINE UNIVERSITY	49	34,1	1,28	1,20	9,2
CALIFORNIA BERKELEY UNIVERSITY	71	48,0	1,11	1,26	6,8
ARKANSAS UNIVERSITY	13	10,1	1,63	1,05	6,4
UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA	29	22,8	1,12	1,29	6,0
MAX PLANCK GESELLSCHAFT	111	52,9	0,98	1,22	6,0
NORTHWESTERN UNIVERSITY (PRC)	58	43,6	1,13	1,29	5,7
WASHINGTON UNIVERSITY	76	56,8	0,83	1,19	5,4
CALIFORNIA LOS ANGELES UNIVERSITY	60	43,5	1,01	1,21	5,2
ILLINOIS UNIVERSITY	68	53,8	1,11	1,29	5,0
CSIC	62	39,1	0,86	1,24	4,7
MELBOURNE UNIVERSITY	25	18,9	1,24	1,37	4,6
NATL CHENG KUNG UNIVERSITY	122	95,8	0,70	1,19	4,4
WISCONSIN UNIVERSITY	63	47,7	0,81	1,23	4,1
STANFORD UNIVERSITY	41	27,4	0,91	1,22	4,1
FLORIDA UNIVERSITY	30	22,8	0,90	1,32	4,0

The "number of companies" indicator gives an impression of the number of companies working with nanotechnology for healthcare applications, and their geographical distribution. These results are consistent with the findings from the other sectors, indicating no particularly geographical specialisation for companies in this area.

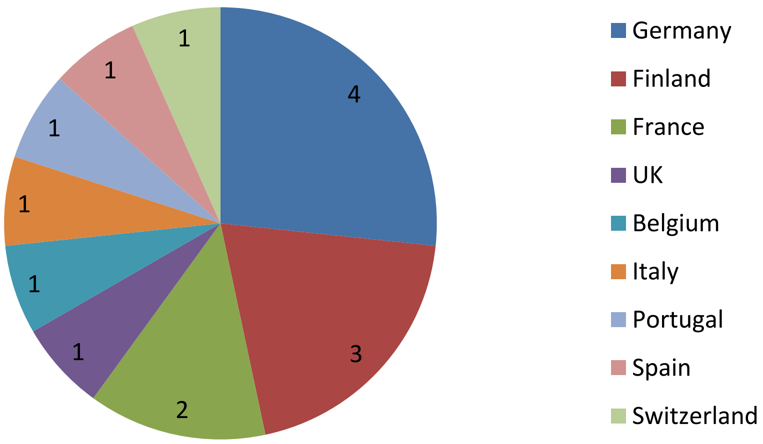

Figure 28. Number of companies who self-identify in healthcare sector, by country

The “number of employees” indicator gives the lower and upper estimates for employment in this sector (amongst the respondents to the survey). The average number of employees is the lowest of the areas covered so far, which combined with the similar number of companies, suggests that nanotechnology companies in this area have a low headcount. Taken with the venture capital indicator, this could also suggest that the landscape consists of several very small firms and a handful of venture-capital fuelled, larger entities.

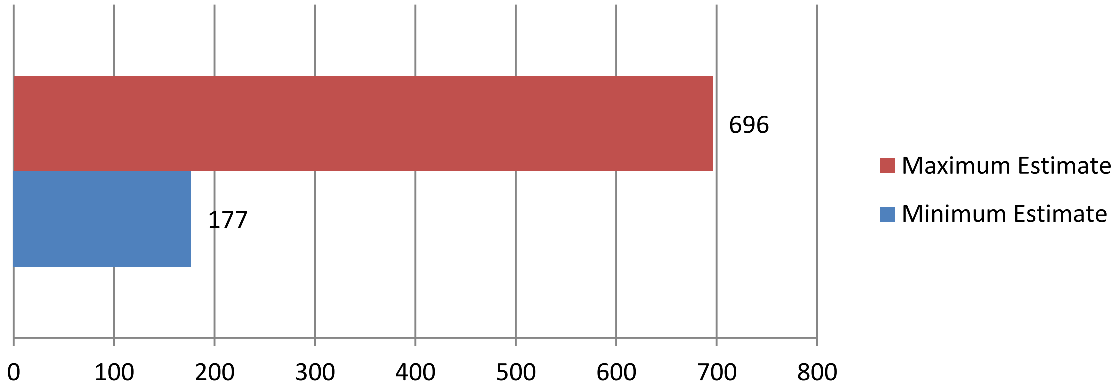

Figure 29. Estimated number of employees, min and max

6. NANOMATERIALS

6.1 Impact of Nanotechnology

This case covers the production of nanomaterials, including carbon nanotubes (CNTs) and fullerenes, nanoparticles (e.g. TiO2) and their use in intermediate products, bulk materials and coatings.

Development in this sector has been characterised by discovery of nanomaterials on a roughly 10 year cycle; fullerenes, CNTs, graphene etc. This typically leads to a significant increase in research into the production and properties of such materials, as well as the identification of potential industrial applications.

Commercialisation is carried out both by new firms and by established industrial players, Nanocyl and Bayer Material Science in CNTs for example. A nanomaterials value chain emerges, in which manufacturers of nanomaterials sell their products to intermediate firms who will integrate them into a material, which is then sold to a consumer of this material. This would involve a nanomaterial producer selling to a coatings firm who would then sell the coatings to an automotive manufacturer, for example.

The commercialisation challenge is on the one hand for nanomaterial producers with multiple potential applications to identify and pursue those which are most valuable, whilst also understand and gain entry to the value chains that exist in those industries.

6.2 Indicators-based examples

The venture capital data set tracked EUR 37 million of investments in nanomaterials companies in Europe, across a total of eight individual deals. The five largest deals are shown below.

Table 8. Sample of recent venture capital investments in companies developing nanomaterials

Company	Country	Value (€)	Investor	Date
ItN Nanovation	Germany	11 000 000	RusNano	31.8.2011
Beneq	Finland	9 000 000	Finnish Industry Investment, Via Venture Partners and private investors	10.1.2011
P2i Ltd	UK	6 345 680	Naxos Capital Partners, Swarraton Partners, Porton Capital, Unilever Ventures and Rainbow Seedfund	1.5.2010
Carbodeon	Finland	5 000 000	Enso Holding Ltd	10.12.2010
Surrey Nanosystems	UK	2 879 300	Octopus Ventures, IP Group, The University of Surrey and other investors.	24.8.2009

This sector has aroused interest from investors, with investment going mainly to companies working with nano-intermediates, for which they have identified specific and high value applications, such as water repellent textile coatings in the case of P2i. The data also suggests investor interest in companies in the overlapping area of materials and equipment – both Beneq and Surrey Nanosystems manufacture deposition equipment.

Nanotechnology research production output in the sector is measured by the number of scientific articles. The figure below shows the development in the number of publications in the major regions between 2004 and 2011. This field has the highest number of publications overall, with the number of European publications in 2008 (1650) four times that found in the Energy sector (375). The story of increasing Asian research output repeats here, though to a lesser extent than in Energy or Environment. This is also notable for being the only area in which European publications exceed those of the US-Canada. In general this can be seen as an extensive and broadly distributed field showing significant rates of increased activity.

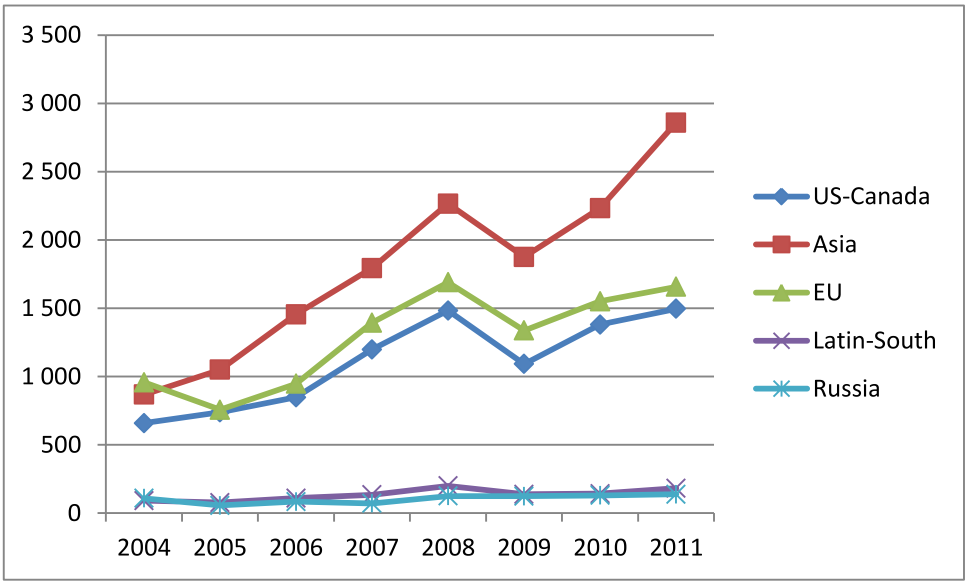

Figure 30: Number of papers (P) per World region during 2004-2011.

Another way to measure sectoral publishing activity is to use fractional counts. This indicator gives a figure of weight for the contribution of the group to the quantitative indicators of all their papers and is a way of controlling the effect of collaboration when measuring output and impact. The figure below shows the development in the number of fractionalised publications in the major regions between 2004 and 2011. Asian countries (China, Taiwan, Japan, South Korea, and Singapore) have a pronounced growth of papers over the period. The same cannot be said about Europe and US-Canada; both seem to have a standstill in their paper production.

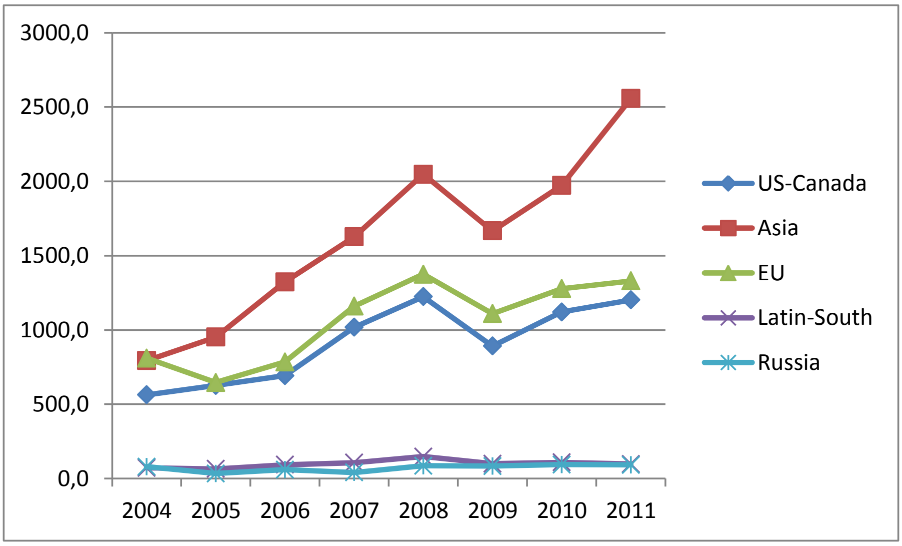

Figure 31. Number of fractionalized papers (Frac P) during 2004-2011.

Citations are a way to measure the quality of research. It provides a reasonable estimate of the importance and impact of nanotechnology research accomplishments. Figure 32 below shows the development in the quality of research by using the standardized citation score (SCS) in the major regions between 2004 and 2010. Several distinct SCS quality bands emerge. US-Canada is third in publication count but first in publication quality, suggesting a greater focus on higher quality research. Europe’s research is of a substantially higher quality than that of Asia, and the quality gap between the two regions is increasing. Encouragingly for Europe, EU and US-Canada quality scores are showing signs of convergence.

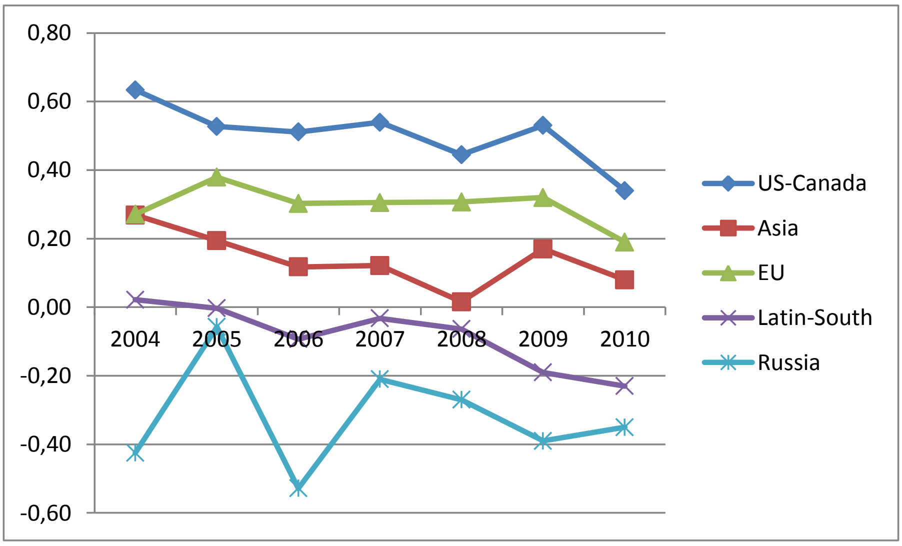

Figure 32. Standardized Citation Score (SCS) per World region during the period 2004-2010.

Another indicator measuring the quality of research is the share of papers in the top 5% of cited papers. This indicator aims specifically to reveal top level research activity. The figure below shows the development in the quality of research by using the Top 5% indicator in the major regions between 2004 and 2010. The pattern is similar as for SCS scores – the US provides a large share of the highest quality research, though Europe's representation among the top 5% of papers increased at least marginally. Asian papers are at the same time getting better and better.

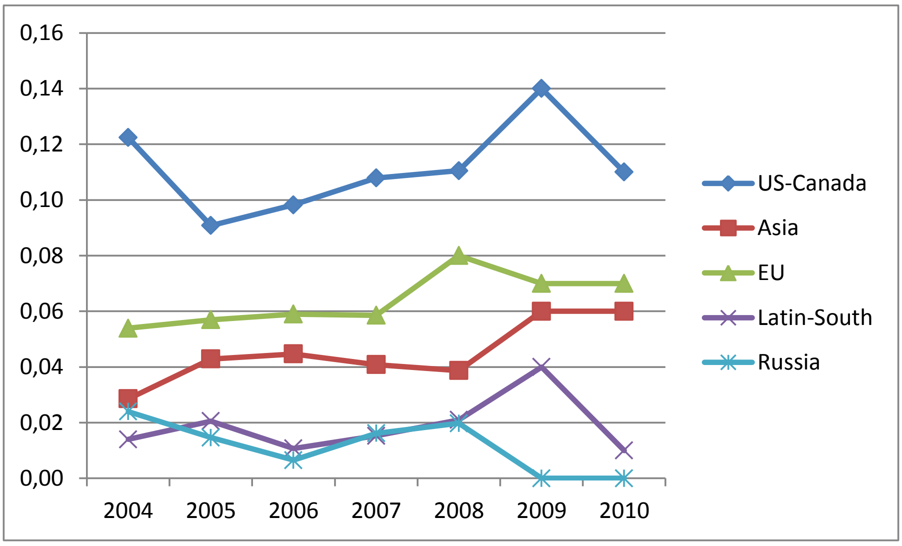

Figure 33. Share of papers in TOP5% per World region during the period 2004-2010.

The "vitality" of research article references is measured as the average age of all cited references from the papers. This Vitality indicates researcher's willingness to attack new problems with new measures and therefore acts as an estimate for diversity and dynamics within the research and innovation system. The figure below shows the development in the vitality of research in the major regions between 2004 and 2010. As with many of the other indicators analysed, vitality is very consistent across regions, but there is more unified picture in 2008, maybe because of a major breakthrough in nanoscience, e.g. graphene.

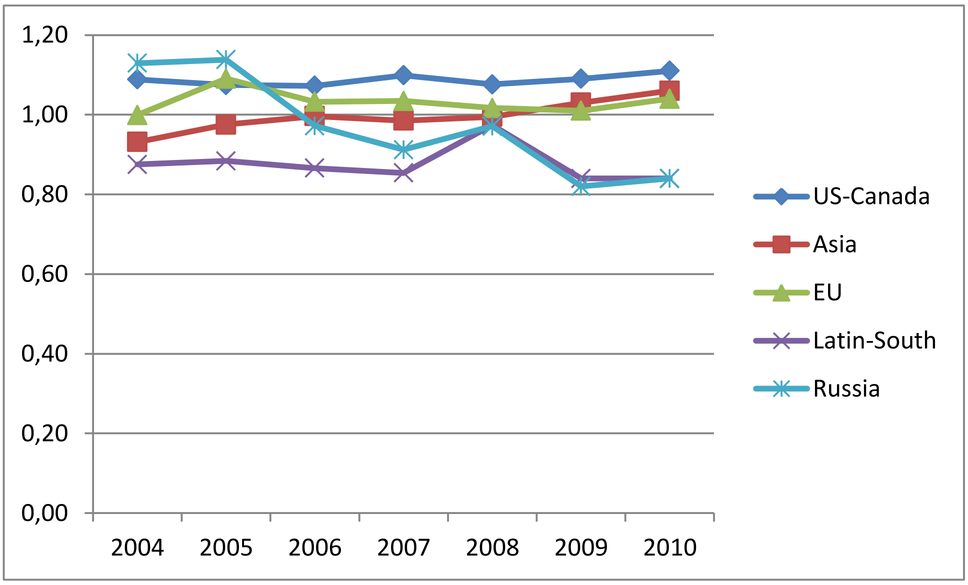

Figure 34. Reference recency (VITALITY) per World region during the period 2004-2010.

The Table below shows the most prolific organisations active in nanomaterials research during 2004-2010. We apply the same method as described above using the combined indicator “IMPACT”. Once again, there is a concentration of American academic research institutions, but the Chinese are at the very top, less so due to high citation scores (see SCS indicator). The institution which ‘punch above their weight’ in this ranking do correlate with known areas of specific expertise, i.e. research on reactive surfaces at Crete University.

Table 9. High IMPACT institutions plus performance indicators in Nanomaterials research 2004-2008.

Organisation Materials	P	Frac P	SCS	VITALITY	IMPACT
CHINESE ACADEMY OF SCIENCES	789	554,4	0,53	1,08	13,9
NORTHWESTERN UNIVERSITY (PRC)	103	72,0	1,07	1,18	11,9
MAX PLANCK GESELLSCHAFT	245	139,3	0,88	1,10	10,8
MASSACHUSETTS UNIVERSITY	45	25,5	1,31	1,12	8,2
CALIFORNIA RIVERSIDE UNIVERSITY	63	49,8	0,94	1,22	7,8
IBM CORPORATION	37	24,2	1,24	1,28	7,5
MIT	108	67,8	0,94	1,30	7,2
RICE UNIVERSITY	70	49,0	1,04	1,29	7,1
OHIO STATE UNIVERSITY	116	85,4	0,63	1,16	6,5
NATL UNIVERSITY SINGAPORE	144	101,2	0,74	1,14	6,5
DREXEL UNIVERSITY	38	22,5	1,26	1,30	6,4
JOHNS HOPKINS UNIVERSITY	58	36,4	1,11	1,25	5,5
CALIFORNIA BERKELEY UNIVERSITY	121	73,6	0,77	1,10	5,0
POHANG UNIVERSITY SCI & TECHNOL	113	68,2	0,59	1,04	4,7
SO CALIFORNIA UNIVERSITY	97	52,6	0,91	1,19	4,6
CRETE UNIVERSITY	24	15,6	1,02	1,10	4,6
CALIFORNIA LOS ANGELES UNIVERSITY	49	31,0	1,12	1,12	4,3
STANFORD UNIVERSITY	60	42,5	0,82	1,20	4,3
DEAKIN UNIVERSITY	45	33,7	1,01	0,98	4,1

The "number of companies" indicator gives an impression of the number of companies working with nanotechnology for nanomaterials applications, and their geographical distribution. As suggested by the other indicators, the number of companies in the sample (27) is substantially higher than in the other sectors. As would be expected from a sector which includes such a wide range of activities, companies using nanomaterials are evenly distributed around Europe.

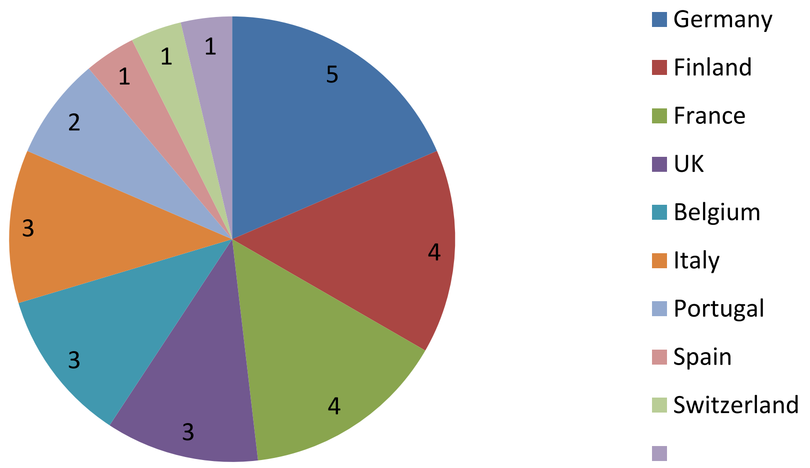

Figure 35: Number of companies who self-identify in materials sector, by country

The "number of employees" indicator gives the lower and upper estimates for employment in this sector amongst the respondents to the survey. The very wide bounds for the employment estimates are caused by the presence of several large companies, as a company with 1000+ employees reporting 1-25% of employees working with nanotechnology could account for 1-250+ employees.

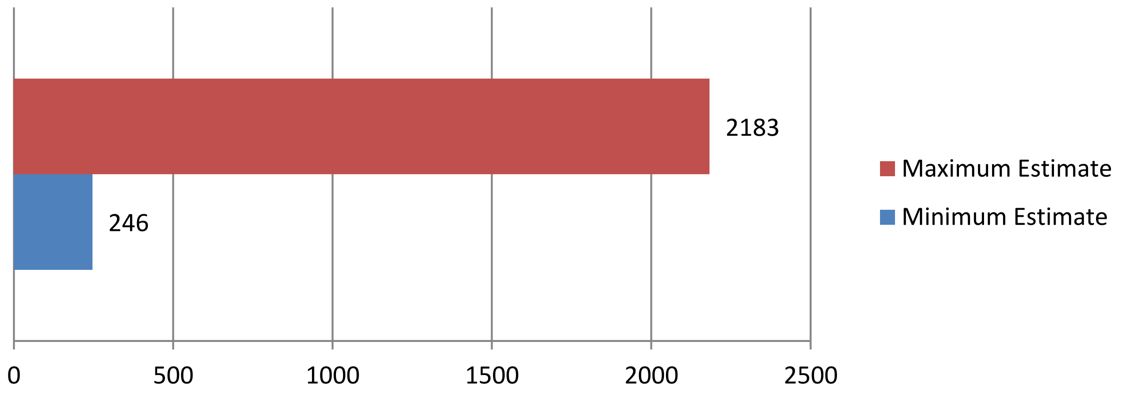

Figure 36: Estimated number of employees (Min and Max)

7. CONCLUSIONS

Based on the case study analysis it can be concluded that it is possible to create sector specific indicators on the development of NST. However, a sectoral approach requires both more effort in collecting data as well as specific care when analysing the results.

Firstly, NST does not fall in any one existing scientific or sectoral classification and therefore in each dataset a specific sectoral classification has to be defined in order to extract the sector specific data. This typically means that there is very little sector specific data readily available but instead this needs to be extracted separately for each indicator. For example for bibliometric data one needs to first define NST specific data and then the sector specific data from this. The process of definition is time consuming and requires knowledge on sector specific aspects of NST. The sectors also differ in the use of NST. Some sectors of NST can be very close to the core activity of companies (e.g. nanomaterials) and therefore the impact of NST is somewhat easier to define. In other sectors, such as environment, the use of NST is much more indirect in many applications and the role of NST is more difficult to capture.

Secondly, this situation where NST has to be specifically defined for each dataset naturally results in a situation where individual indicators in the same sector are not easily comparable i.e. the definition of “energy sector” in bibliometric data is different than “energy sector” in the company survey.

However, even despite these difficulties in obtaining sector specific data and the differences in how sectors are defined, sectoral NST indicators can be useful by monitoring the development of individual phenomena. It is therefore suggested that not all indicators are selected for sectoral study but a few key indicators that are monitored through time.

European Commission

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Public investments in nanotechnology have thus far largely supported fairly broad based scientific research. It is now time to take stock of the situation by synthesising the latest data available on research and economic activity in nanotechnology, to develop and follow-up indicators, and to formulate strategy options for a European nanotechnology R&D strategy. The NANOMETRICS study establishes a monitoring system that allows to collect data for monitoring the economic and innovation performance of a range of sectors of economy in which nanosciences & nanotechnologies do or could play a significant role. *Part I: Monitoring System*, develops metrics to examine how nanoscale research, products, and markets are evolving over time. *Part II: Case Studies*, presents detailed analyses of selected key domains.

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