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NANORUCER

"Mapping the NANOtechnology innovation system of RUssia for preparing future Cooperations between the EU and Russia"

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1 Introduction

The overall aim of the NANORUCER support activity is to pave the way for future cooperation between the EU and the Russian Federation in the field of nanotechnology and nanostructured materials research (NN) as formulated in the description of the NMP work programme topic addressed. Three specific objectives will deliver this overall aim through the corresponding work packages. The performance analysis carried out in work package 2 will provide important contributions to achieving objective 1 - the mapping of nanotechnology and nanostructured materials activities in Russia. This analysis will provide complementary objective information to the survey and expert-based empirical work to be carried out in work package 3. In particular the performance analysis will provide objective information on the performance of specific subsystems of the sectoral innovation system in nanotechnology of Russia. Two specific functions of the sectoral innovation system will be considered in detail: the generation of scientific knowledge and the transformation and application of this knowledge into the development of technologies, processes and new products. Indicators will be used to measure these functions.

Scientific activities will be measured by their output in terms of scientific publications using bibliometric indicators. Technological and developmental output, on the other hand, will be detected by using patent indicators which have proven to be very useful measures for technology- and application-oriented activities of the respective subsystems of the sectoral innovation system.

The focus of the performance analysis will be on comparisons of the functions of the Russian nanotechnology innovation system in relation to Europe and important other countries such as the USA, Japan and China. Results will comprise objective information on scientific and technological output, specialisation of countries in NN and overlap in R&D activities in particular between Russia and EU Member States, overall performance related to main competitors, key players and most important countries.

We should like to mention that the goal of this analysis is not to reveal a ranking of different countries in terms of their performance in nanotechnology. Rather, we aim at providing information on specialisation, on relative strengths and weaknesses, on focal points of research and technology development activities, and on overlaps of activities between countries which point to possible future cooperative activities. We are well aware of the fact that science and technology indicators such as publication-based and patent-based measures are influenced by a number of factors not least language biases, different country-specific prospensities to patenting and publishing, different traditions in various scientific disciplines in terms of writing publications and not least field specificities which all can have an impact on the overall indicator values. For that purpose the performance analysis is only one piece of information of the overall NANORUCER mapping activities which will be complemented by various other different sources.

In the following paper we will start with the presentation and discussion of the publication analysis, assuming that scientific activities as indicated by publication records provide the ground for applied research, technological development, process and product development. As indicators for the latter more application-oriented activities we will use patent indicators which will be discussed in chapter 3.

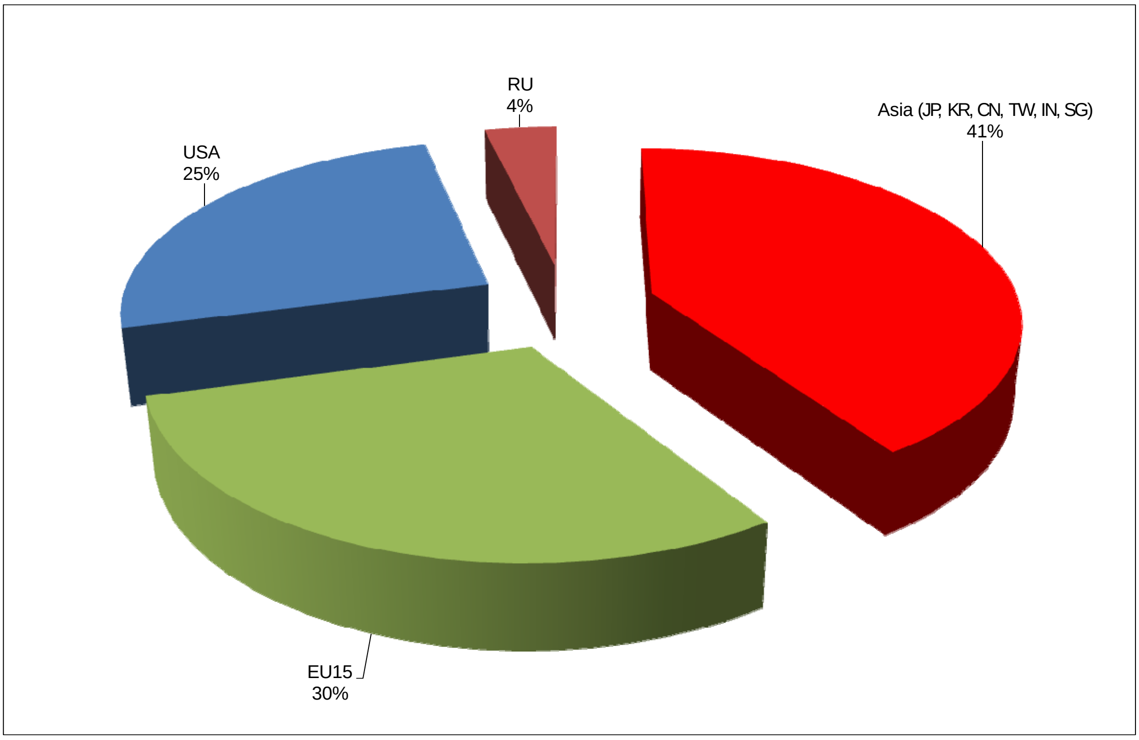
The methodology applied for bibliometric and patent analyses will be described in the annex to this report.

2 Publication analyses

2.1 Worldwide publications in nanotechnologies and the Russian position

In order to obtain a first overview of worldwide publication activities in nanotechnology, we retrieved all publications during the period 2000-2009 from the SCI and analysed the contributions of different world regions to the total publication counts (figure 2.1). Accordingly, the Asian region as defined by the most active countries Japan, Korea, China, Taiwan, India and Singapore was publishing most nanotechnology papers, achieving a share of 41 % of the total of 432,004 publications identified by the search strategy used. Europe, defined as EU15[1], contributed about 30 % and the United States 25 % of total publications. Russia obtained a considerable share of 4 % of all worldwide publications.

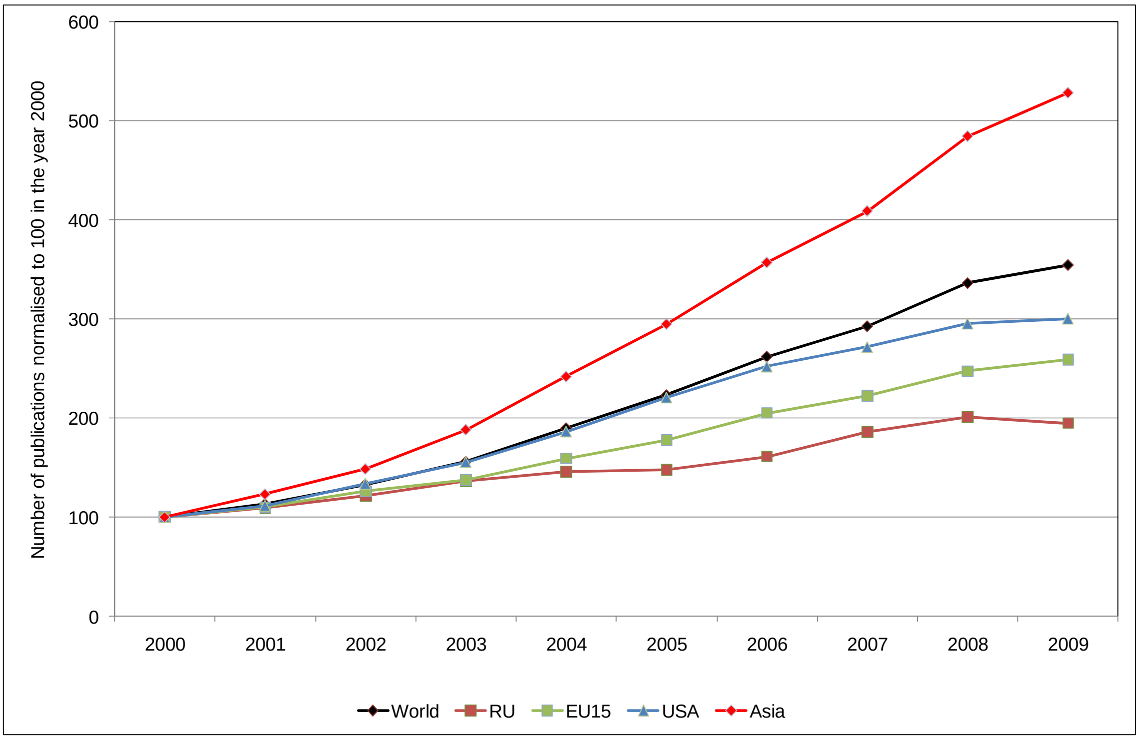
Figure 2.1: Share of world regions in total nanotechnology publications over the period 2000-2009



1 EU15 covers more than 90 % of all publications of EU27 (for details see annex methodology)

Scientific activities in nanotechnology as measured by publication output developed very dynamically over the ten-years-period considered. On a world level the number of publications increased by a factor of 3.5 between 2000 and 2009 (figure 2.2). The worldwide growth of nanotechnology publications is in particular remarkable if we compare it to the development of all worldwide publications which increased only by a factor of 1.3 over the ten-years-period considered. The most dynamic region was Asia where we observe an increase by a factor of almost 5.5 during this period. The Asian growth is mainly driven by China, Korea, India and Taiwan, while we observe a less dynamic development in Japan. But also in the USA, Europe (EU15) and Russia publication activities grew considerably during the last ten years. While the USA could almost triple its publication output, in the case of Russia we observe a doubling of the number of publications.

Figure 2.2: Dynamics of nanotechnology publication activities in different world regions over the period 2000-2009



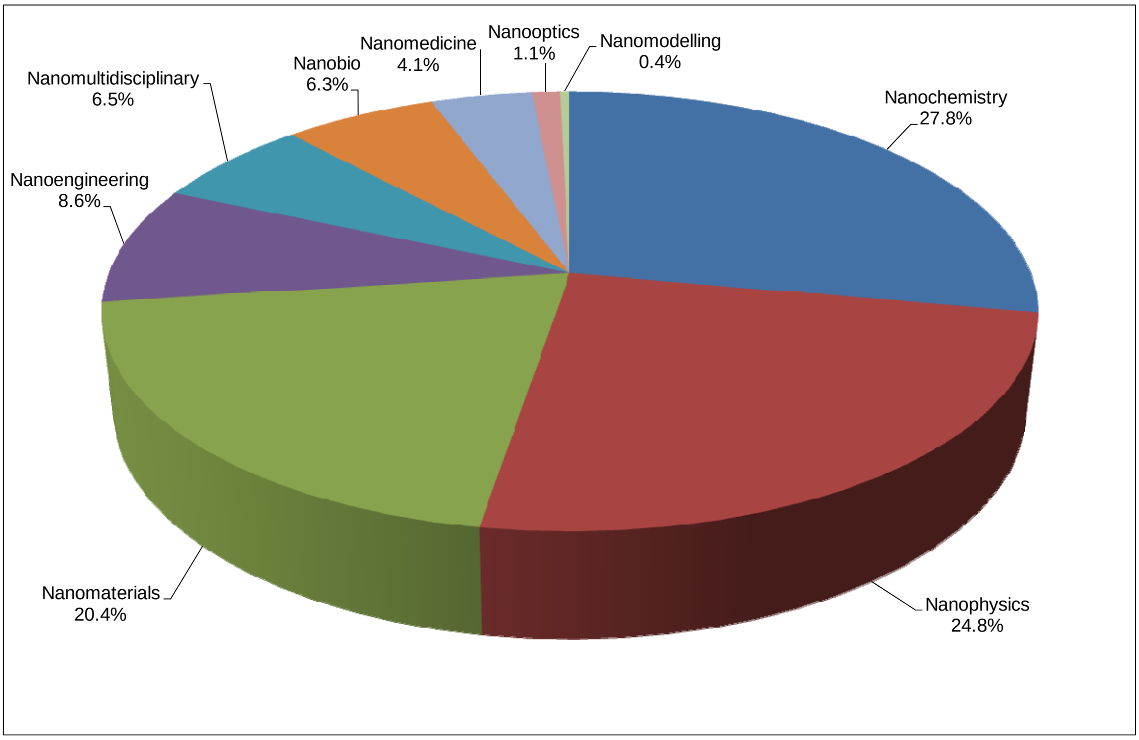
2.2 Comparing Russia and EU countries by nanotechnology fields

In this section we will explore in more details the focal points of research activities in different nanotechnology subareas in Russia compared to other European and world regions. For that purpose we divide the total field of nanotechnology into the following subfields: nanochemistry, nanophysics, nanomaterials, nanoengineering, multidisciplinary nanoactivities, nanobio, nanomedicine, nanooptics and nanomodelling (for more details see annex).

As indicated by publication activities these fields vary considerably in size. We observe three large fields - nanomaterials, nanophysics and nanochemistry making together more than 70 % of all nanotechnology publications (figure 2.3).

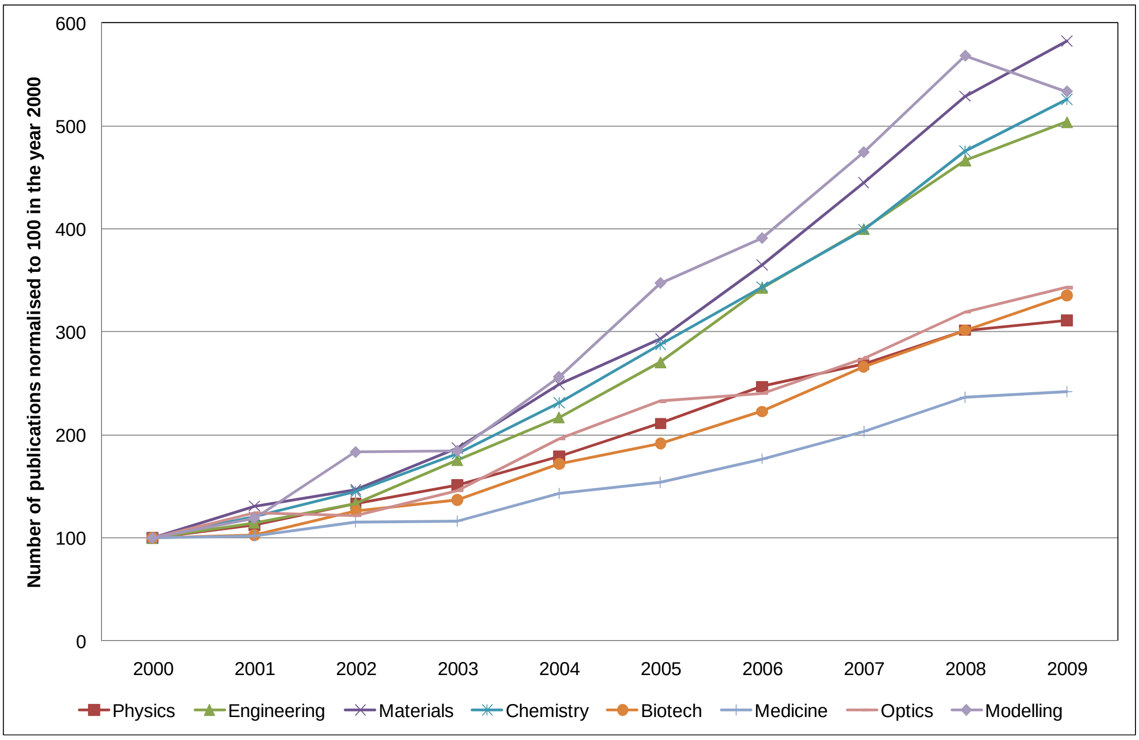
On the other hand, nanomodelling and nanooptics belong to the smaller fields contributing 0.4 and 1.1 %, respectively to all publications. The other fields range between 4.1 and 8.6 %.

Figure 2.3: Share of different nano fields in total worldwide publications over the period 2000-2009



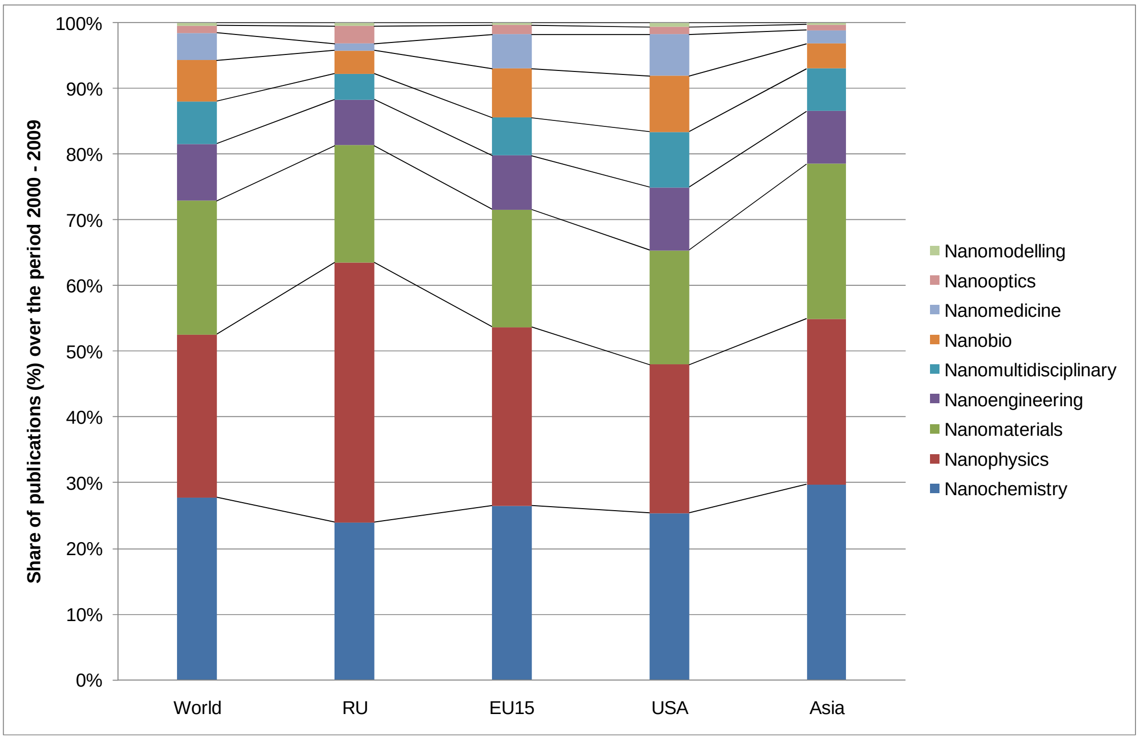
In order to test whether these fields developed differently over the ten-years-period considered, we also measured the time-courses for each field over this period (figure 2.4). We can differentiate these fields into three groups: there is one group (nanoengineering, nanochemistry, nanomodelling and nanomaterials) with a very strong dynamics increasing in size by a factor between 5 and 6 from 2000-2009. Most remarkable is this strong growth of the larger two fields nanomaterials and nanochemistry. In the case of small fields such as nanomodelling growth figures need to be taken with some caution since they are also due to size-effects. A second group of fields is characterised by a growth factor of roughly three over the ten-years-period. This includes nanophysics, nanooptics and nanobio. Again, the strong growth in the case of the large field nanophysics is impressing. Finally, nanomedicine seems to be a less dynamic field with a growth rate of little more than two during the last ten years and there seems to be a levelling out of growth dynamics between 2008 and 2009 for this field.

Figure 2.4: Publication dynamics of nanotechnology subfields over the period 2000-2009 normalised to 100 in the year 2000



In order to obtain a first impression of different specialisations of the regions considered, we analysed the share of publications in nano subfields in all publications for the four regions Russia, Europe (EU15), USA and Asia (defined as described above). As shown in figure 2.5 Russia seems to be different from the other world regions in terms of focal activities mainly in two ways. Firstly, looking at the smaller fields there is a much stronger focus on nanooptics in Russia, while nanomedicine seems to be less important. Concerning the larger fields, Russia has the strongest focus on nanophysics compared to the other regions of the world.

Figure 2.5: Publication shares of nano fields over the period 2000-2009 for different world regions



These differences are also illustrated if we have a closer look at the publication shares of nano fields in Russia compared to EU15 as indicated in figures 2.6 and 2.7. While nanochemistry and nanomaterials seem to be of similar significance in terms of focal activities in both regions, again we observe a strong focus of Russia in the field of nanophysics. The intersection between nanotechnology and life sciences as indicated by publications in nanomedicine and nanobio seems to be more important in the EU15.

Figure 2.6: Publication share of nano fields in Russia over the period 2000-2009

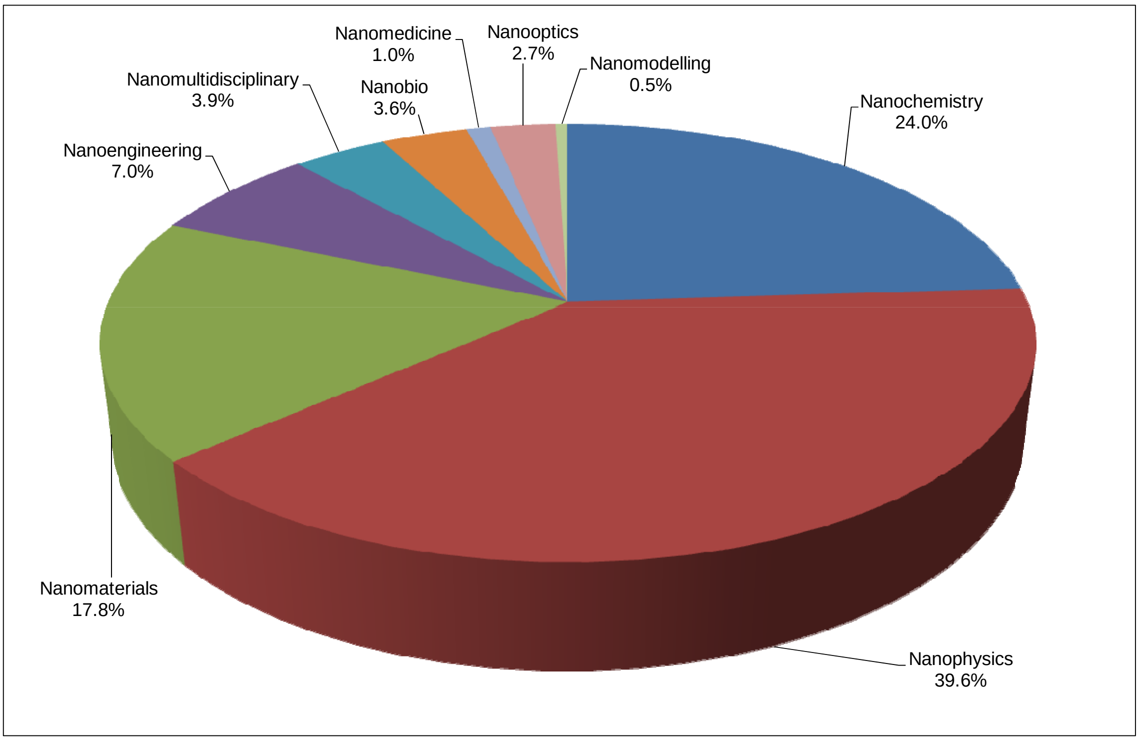
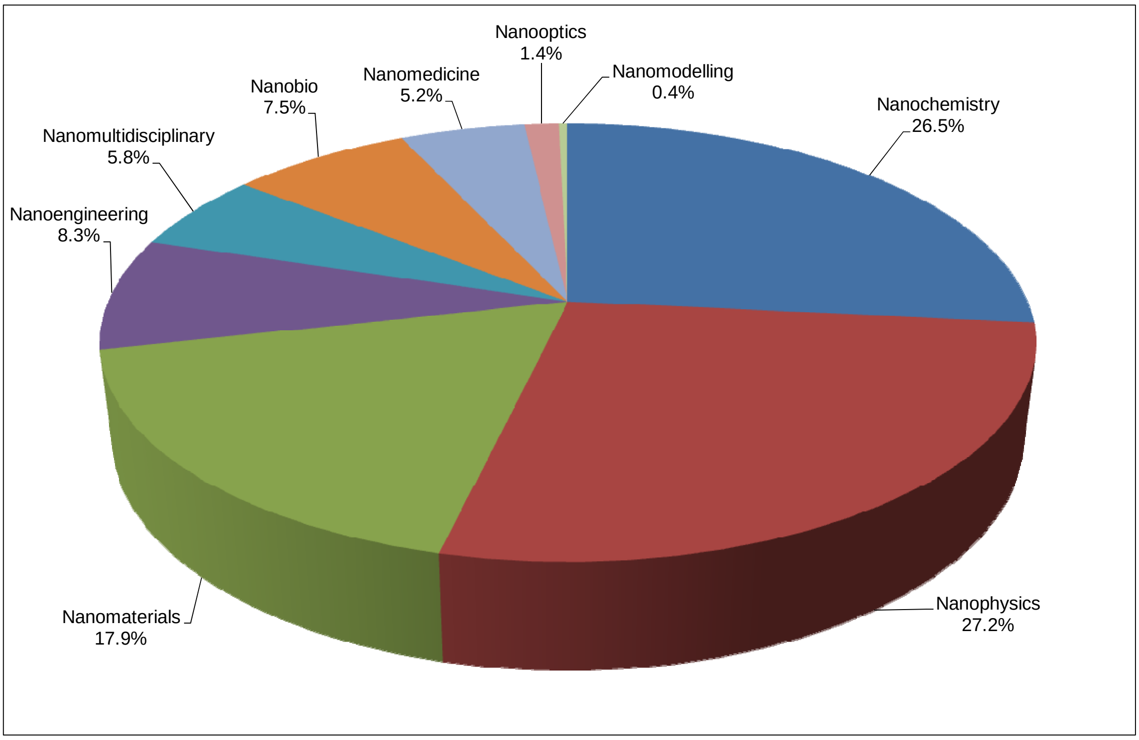


Figure 2.7: Publication share of nano fields in EU15 over the period 2000-2009



Since a major goal of the NANORUCER project is the identification of opportunities for future cooperation between Russia and the EU, it is important to explore how different European countries and Russia contribute to the publication activities in different nanotechnology subfields. Accordingly, we analysed the share of publications from EU15 countries, Switzerland[2] and Russia in the nine nanotechnology subfields described above. The respective results including a graph showing the national contributions to total nanotechnology publications are shown in figures 2.8 to 2.16.

We can identify three fields where Russia belongs to the most active countries in terms of publication output. These include nanophysics (figure 2.8) with a share of 5.17 % of Russian publications, nanooptics (figure 2.14) where Russia contributes a share of 7.59 % to all publications corresponding to a third place just behind France and in front of Great Britain, and nanomodelling, where Russia again ranks at the third place corresponding to 4.14 % of all publications as shown in figure 2.16.

On the other hand, there are two fields namely the life-sciences-related fields nanobiotechnology (figure 2.12) and nanomedicine (figure 2.13), where Russia contributes only low shares to the overall publication record compared to other European countries.

In summary, this analysis could provide some first hints for potential fields of future cooperations. In the case of fields where Russia is an important player in the European context in terms of publication output (nanophysics, nanooptics, nanomodelling), we would expect a rather high number of potential subfields and research groups from Russia being interested in offering cooperation opportunities. On the other hand, in the smaller fields which are mainly concerned with the intersection of nanotechnology and life sciences, identifying potential themes and partners in Russia for cooperation might be more difficult.

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2 Switzerland was included because it is quite active in publishing nanotechnology papers comparable to EU Member States like the Netherlands or Sweden.

Figure 2.8: Share of different countries in worldwide publications in nanophysics over the period 2000-2009

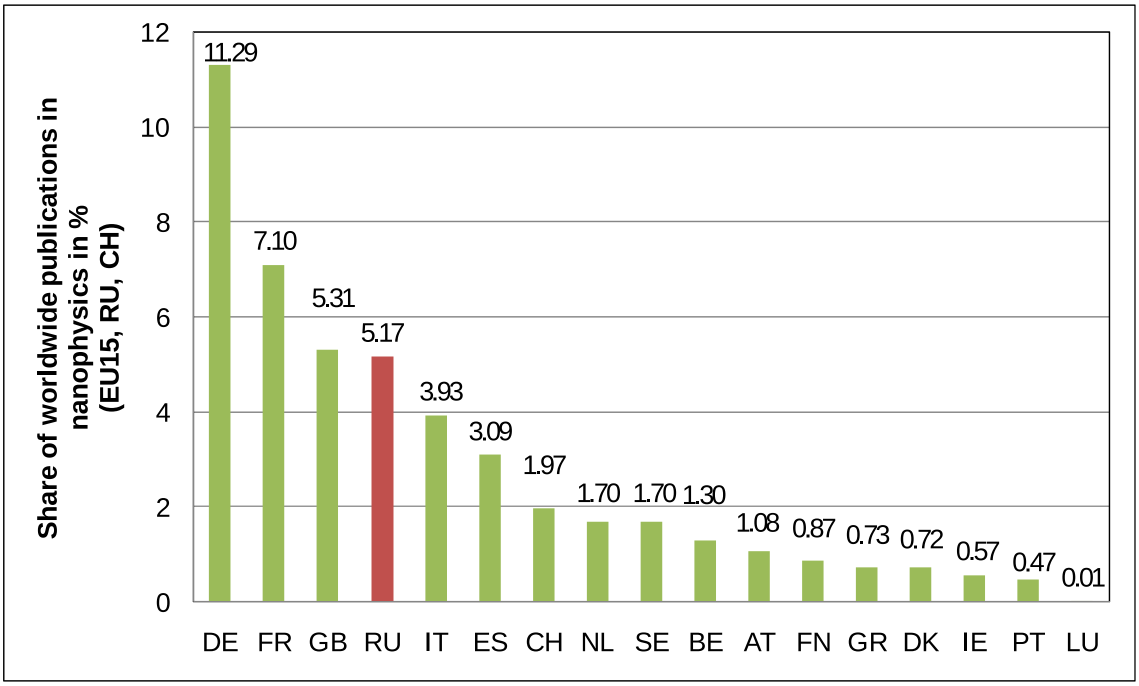


Figure 2.9: Share of different countries in worldwide publications in nanoengineering over the period 2000-2009

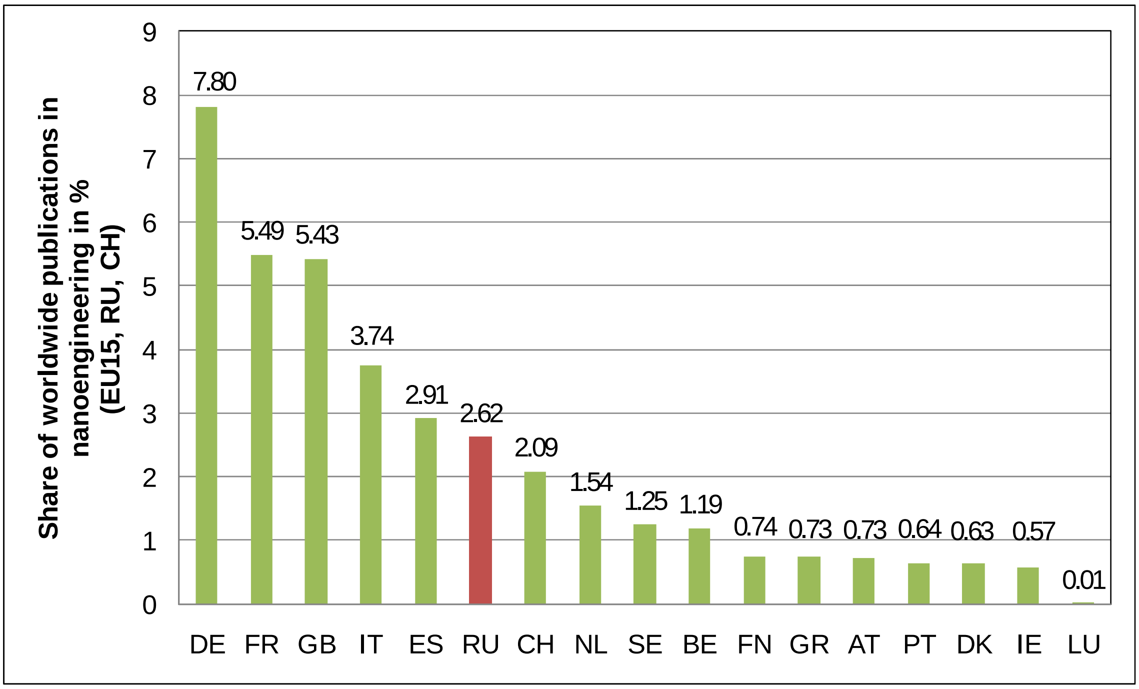


Figure 2.10: Share of different countries in worldwide publications in nanomaterials over the period 2000-2009

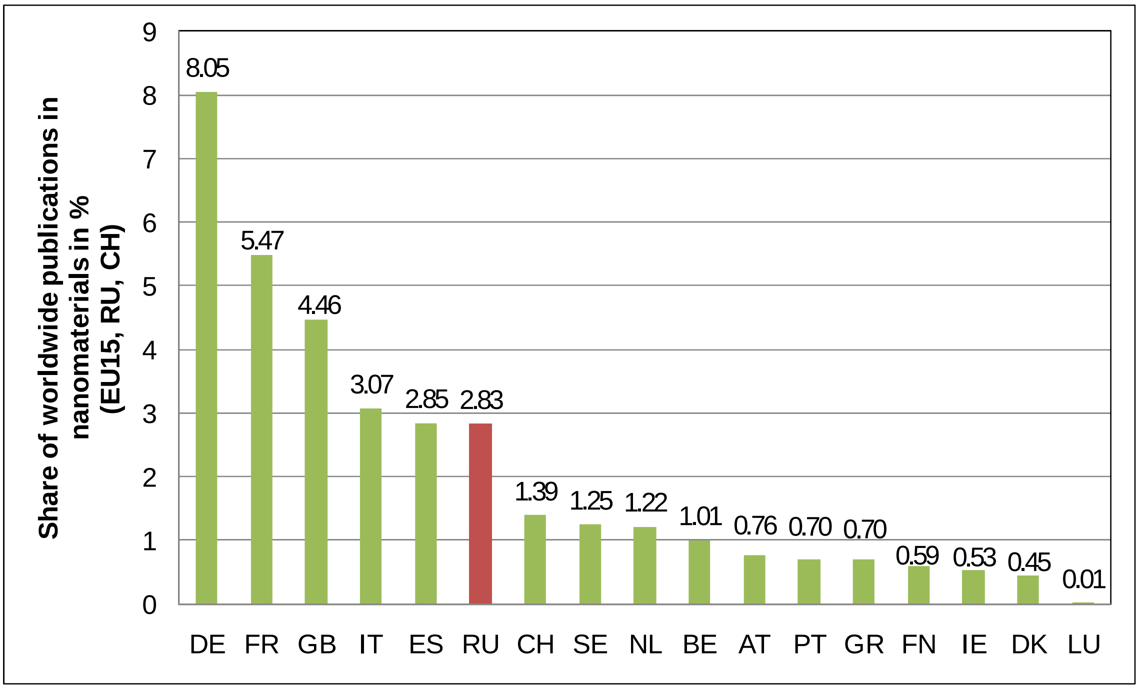


Figure 2.11: Share of different countries in worldwide publications in nanochemistry over the period 2000-2009

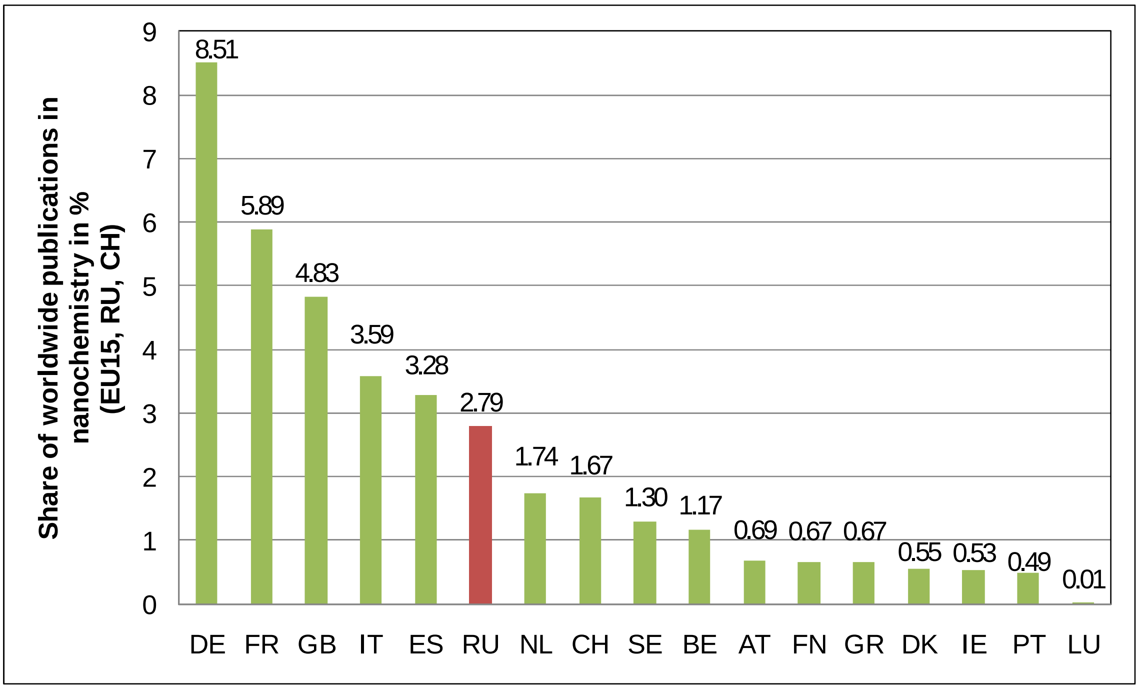


Figure 2.12: Share of different countries in worldwide publications in nanobiotechnology over the period 2000-2009

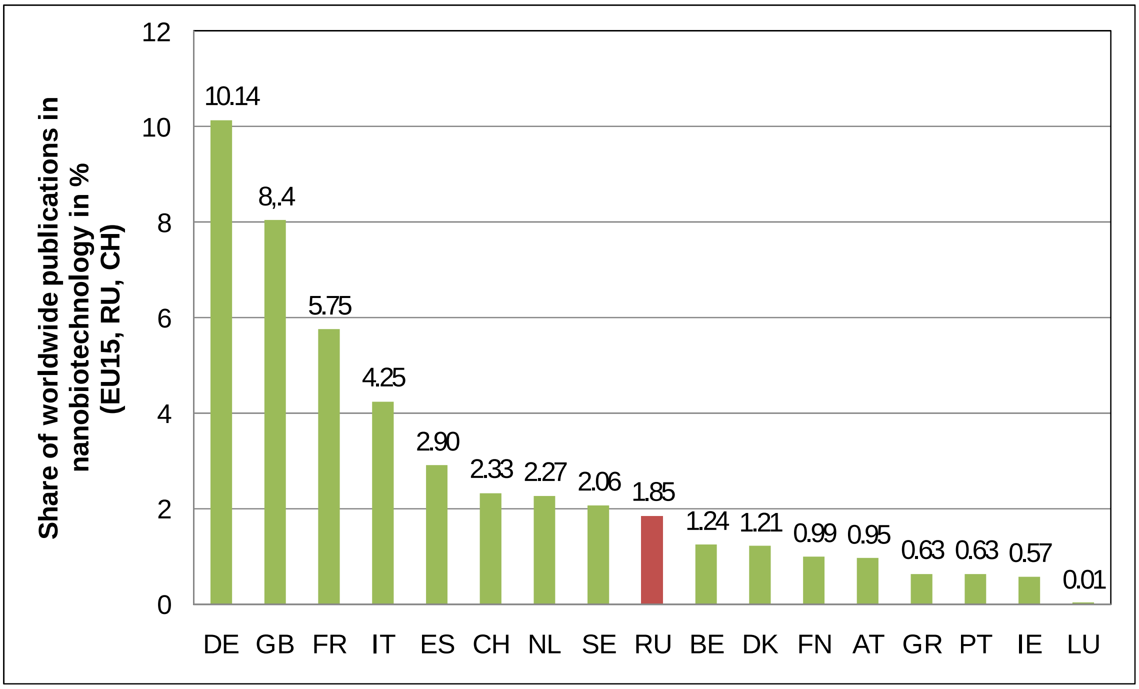


Figure 2.13: Share of different countries in worldwide publications in nanomedicine over the period 2000-2009

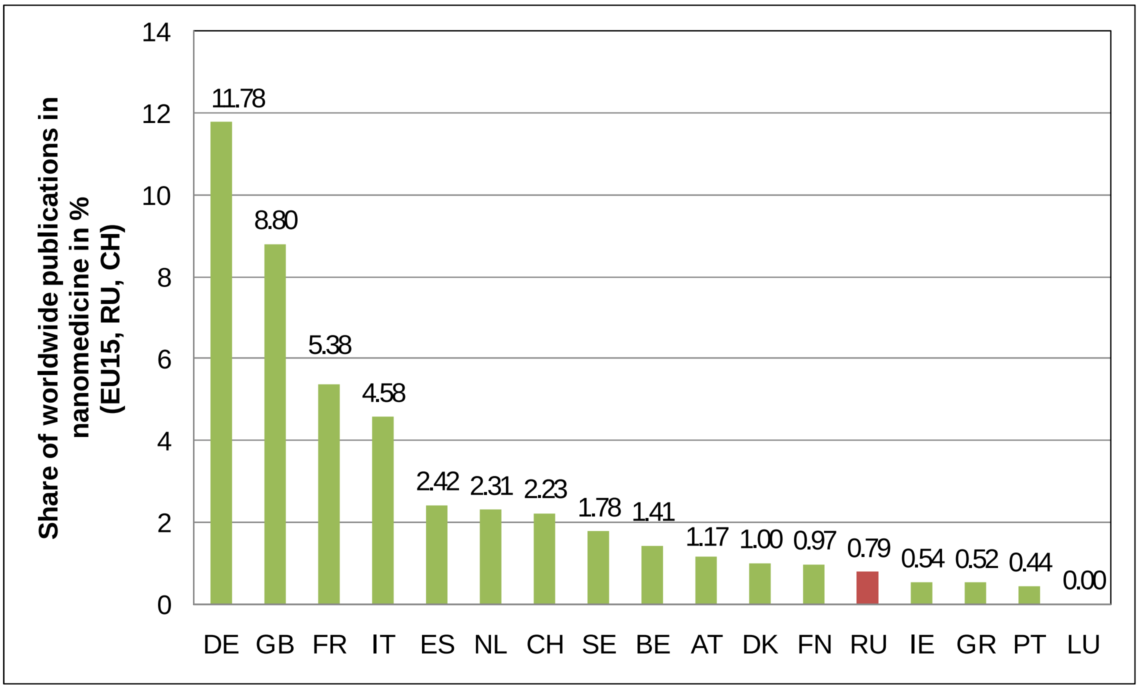


Figure 2.14: Share of different countries in worldwide publications in nanooptics over the period 2000-2009

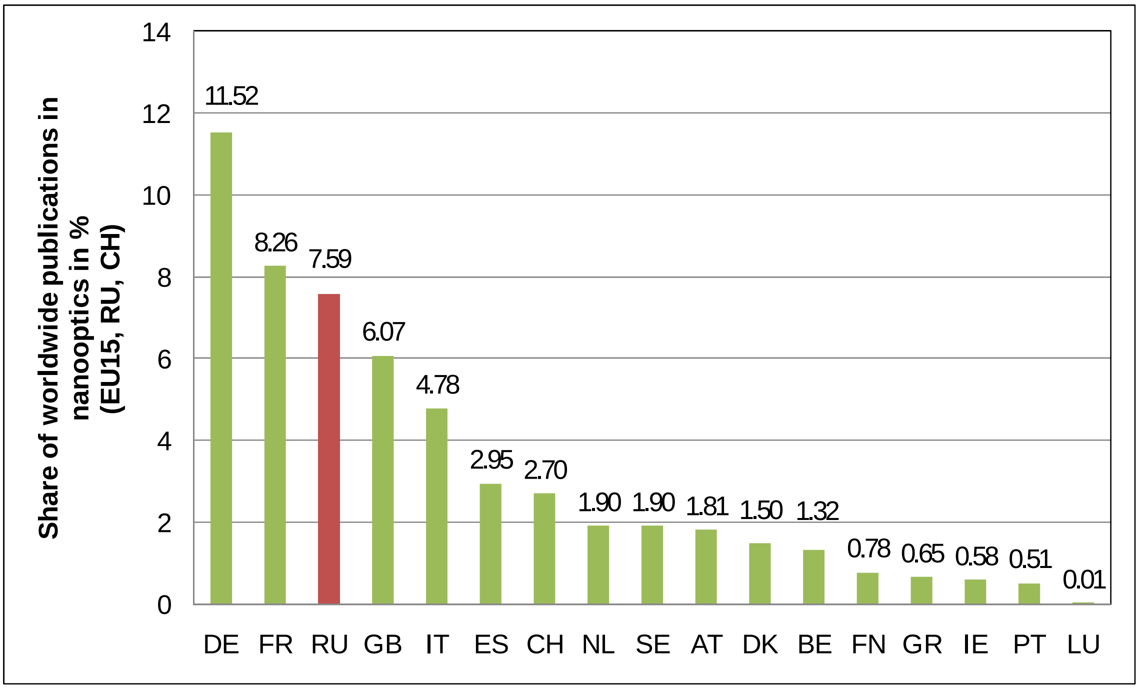


Figure 2.15: Share of different countries in worldwide publications in nanomultidisciplinary over the period 2000-2009

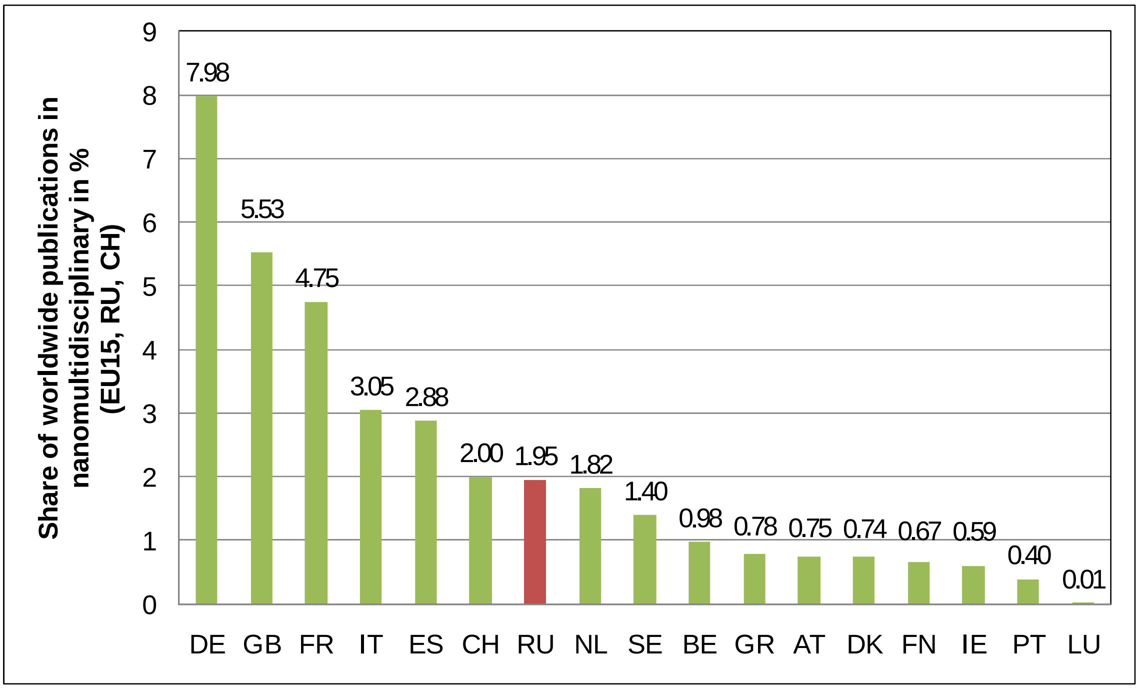
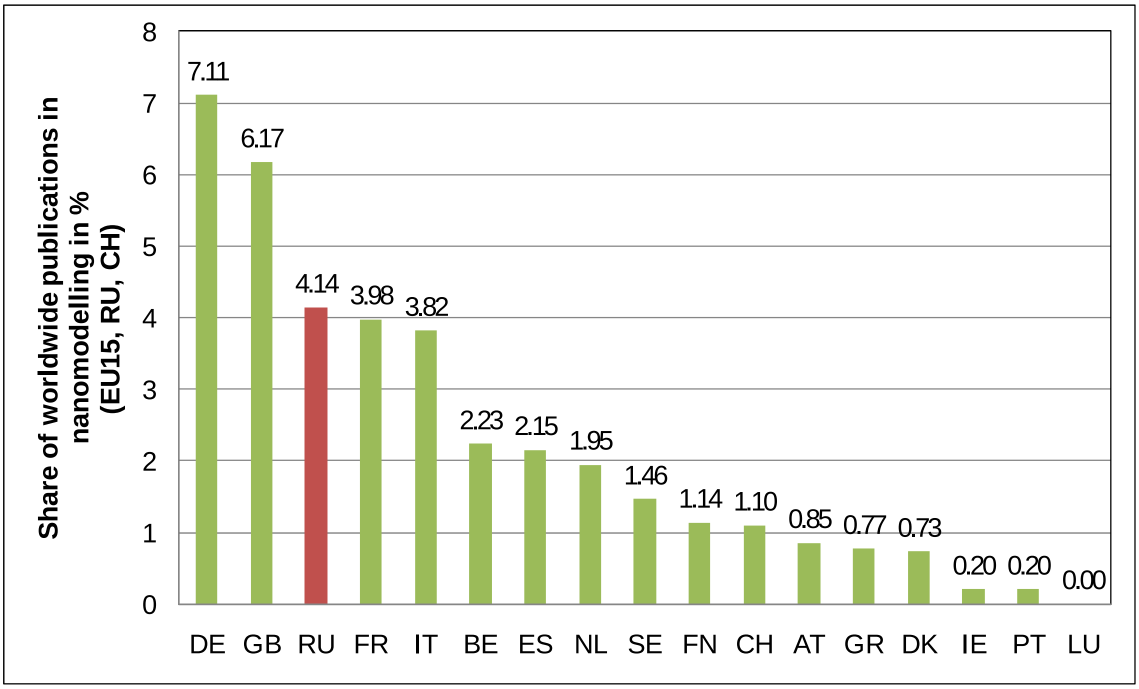


Figure 2.16: Share of different countries in worldwide publications in nanomodelling over the period 2000-2009

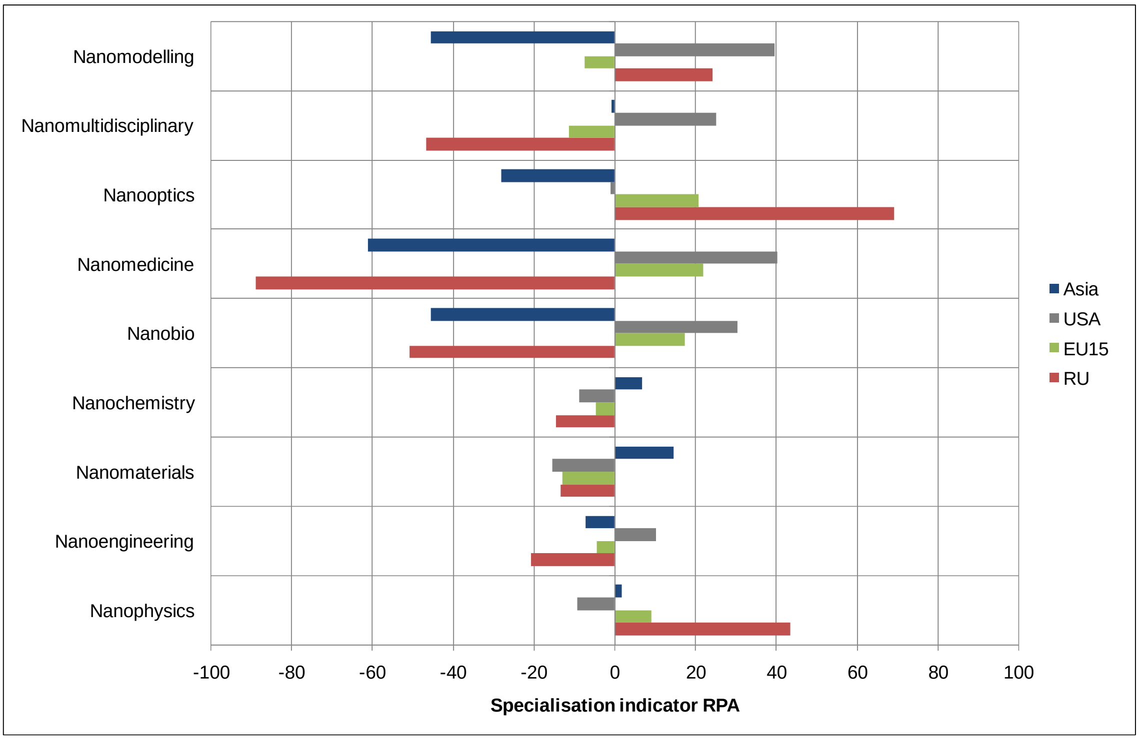


2.3 Relative specialisation of Russia in nanotechnology fields

In this section we will explore in more detail the relative specialisation of Russia and other countries in nanotechnology. For that purpose we will use a specialisation index, the RPA indicator, which basically relates the share of publications of a specific country in a specific field to the share of all publications of this country in all publications worldwide. Thereby this indicator provides information on relative specialisation of different countries, compensating for size-effects and different prospensities.

Figure 2.17 presents the specialisation data for Russia, the EU15, the USA and Asian countries in the nine nanotechnology subfields used for this analysis. As already observed in the previous section, Russia is more specialised in the fields nanomodelling, nanooptics and nanophysics as indicated by the positive values of the RPA indicator in figure 2.17. On the other hand, nanomedicine and nanobiotechnology belong to fields were Russia is underspecialised. Comparing Russia with EU15 indicates that there are only a few fields where both regions exhibit similar specialisations. These include nanooptics and nanophysics. In most other fields we observe opposite or complementary specialisations as illustrated, for example, by nanomedicine and nanobiotechnology where EU15 shows positive specialisation values whereas Russia presents negative indictors. Nanomodelling is another case with positive Russian specialisation and negative European specialisation. Thus, such fields might be interesting for identifying complementary competencies which could be first hints for potential cooperation activities.

Figure 2.17: Specialisation of different regions in nanotechnology publications over the period 2000-2010

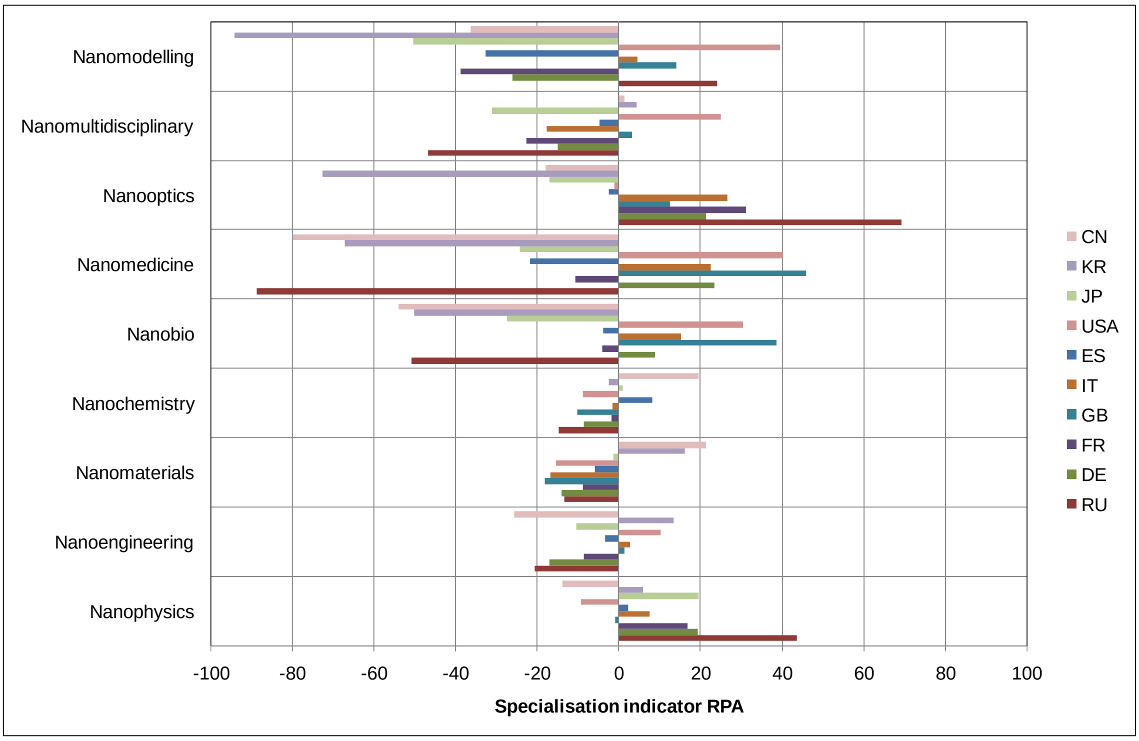


When discussing specialisation patterns it is also of interest to observe changes in specialisation over time. For that purpose we compared specialisation patterns of Russia and EU15 in the nine nano subfields for two different periods: 2000-2004 and 2005-2009 (figure 2.18). This analysis indicates that the specialisation patterns in most fields seem to be rather stable over the two periods considered. Only in the case of modelling we observe changing specialisation of Russia between the two periods. In the former period Russia is slightly specialised in this area, while in the more recent period nanomodelling turns into an area where Russia is less specialised. It should be noted, however, that this observation is based only on a very low number of publications (102 over the ten-years period analysed), and accordingly should be taken with some caution.

Figure 2.18: Comparison of specialisation between Russia and EU15 in nine nanotechnology subfields over two periods: 2000-2004 and 2005-2009

In the following we made a more detailed analysis of specialisation patterns of individual European countries, Asian countries, the USA and Russia (figure 2.19). Interestingly, in most cases Russia presents a similar specialisation pattern as the larger European countries, namely Germany, France, Great Britain and Italy. This is, for example, the case for nanooptics and nanophysics where most of these countries are overspecialised, and nanochemistry, nanomaterials and nanoengineering on the other hand where these countries seem to be less specialised. There are two clear exceptions from this rule namely the life-sciences-related fields, nanomedicine and nanobiotechnology. In these cases Russia is less specialised while most European countries and the United States present stronger specialisation. The Asian countries, China, Korea and Japan, are behaving similarly as Russia in a sense that they are less specialised in the life-sciences-related nanotechnology fields. Another interesting case is nanomodelling. This is the only field where Russia and the United States are the most specialised countries.

Figure 2.19: Specialisation patterns in subfields of nanotechnology for different countries



2.4 Summary of bibliometric analyses

The performance analysis indicates that scientific activities in nanotechnology as measured by publication output increased very rapidly worldwide during the last ten years. We observe an average growth rate of nanotechnology publications of 3.5 compared to an average growth rate of 1.3 over all scientific disciplines. The dynamics of nanotechnology publications is mainly driven by Asian countries (Japan, Korea, China, India and Singapore) and the United States, while in terms of overall publishing activities EU15 is the second most active region with a share of 30 % of all publications compared to 41 % for Asia and 25 % for the USA.

Within the whole field of nanotechnology we observe interesting differences in terms of dynamic development. Nanoengineering, nanochemistry, nanomaterials and nanomodelling comprise subfields with the strongest growth. Interestingly, nanochemistry and nanomaterials also belong to the larger subfields of nanotechnology. Nanophysics, nanooptics, nanobiotechnology and nanomedicine present a less dynamic growth pattern compared with the former fields. These differences indicate that it is important to differentiate within the whole field of nanotechnology when discussing dynamics and country specialisation.

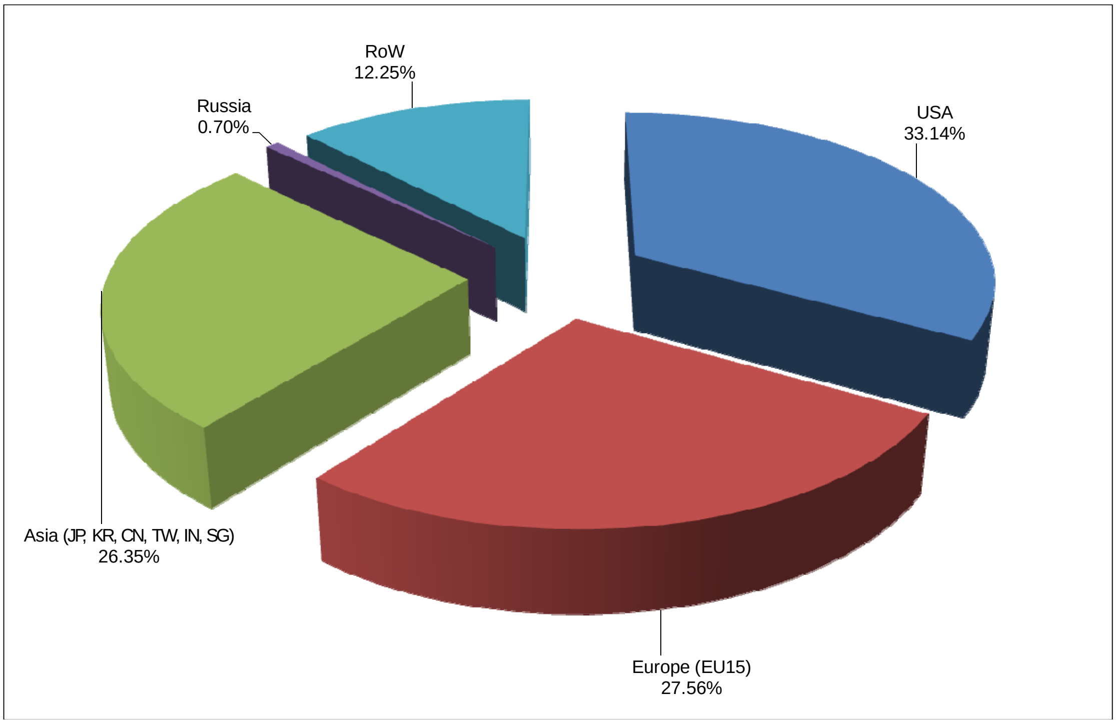
For comparing scientific activities in nanotechnology of Russia with other regions we performed a specialisation analysis. We observe a strong specialisation of Russia in three subfields, namely nanomodelling, nanooptics and nanophysics. Interestingly, nanooptics and nanophysics are also fields where Europe as a whole but also the larger European countries, Germany, France, Great Britain and Italy, present a strong specialisation. Concerning opportunities for future cooperation these fields of mutual strength might be suitable candidates for identifying specific topics for joint activities. We also observe two nanotechnology subfields where the competencies of Russia and European countries could be considered as complementary. These are nanobiotechnology and nanomedicine where we observe a rather strong specialisation of European countries, whereas Russia is less specialised in these topics.

3 Patentanalyses

3.1 Worldwide patenting in nanotechnologies and the Russian position

In analogy to the publication analysis presented in the previous section we firstly provide an overview of the contribution of different world regions to worldwide patenting activities in nanotechnology. For that purpose we analysed the contribution of different regions to worldwide patent applications at the European Patent Office including EP and PCT applications (see annex methodology for details) over the ten-years-period 1997-2006 (figure 3.1). The United States turned out to be the most active contributor to patenting activities achieving a share of about one third of all patent applications. Europe defined as EU15 contributed almost 28 % of all patent applications, a similar share as the Asian countries with roughly 26 %. Russia obtained a share of 0.7 % of all patent applications. If we compare this share of Russia with the corresponding share of Russia in publication activities (4 %, figure 2.1), the prospensity to patenting in Russia seems to be much lower compared to publication prospensities. About 12 % of all patent applications were contributed by the rest of the world (RoW).

Figure 3.1: Share of world regions in total nanotechnology patent applications over the period 1997-2006

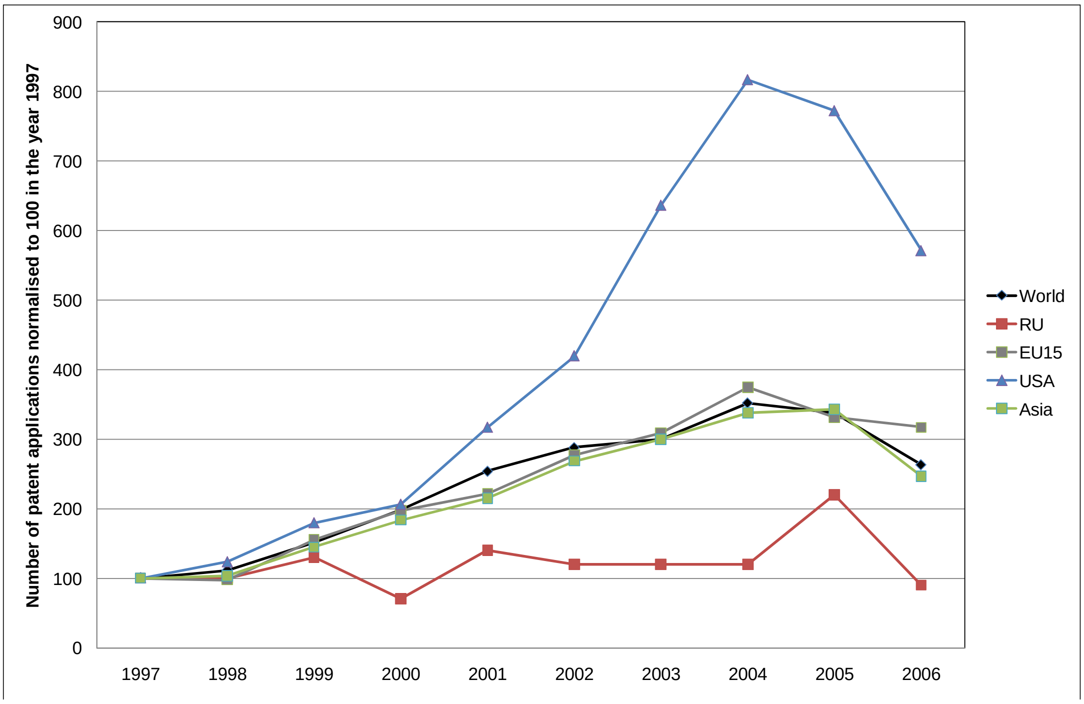


The dynamics of patent applications in nanotechnology in different world regions is shown in figure 3.2. On a world level we observe a rather strong growth of patenting activities between 1997 and 2005 where patent applications grew by a factor of roughly 3.5. Towards 2006 patenting activities seem to drop again. Due to the high share of the USA in all patent applications, the worldwide dynamics is strongly influenced by the behaviour of the United States. For this region we observe a very strong growth of patenting activities by a factor of 8 between 1997 and 2004 followed by a considerable drop towards the year 2006. The dynamics of patenting activities in Europe and Asian countries is similar to the worldwide activities. In the case of Russia we observe a rather stable development with no remarkable growth.

The worldwide decline of nanotechnology patent applications between 2004 and 2006 which is driven largely by the patenting behaviour of the United States seems to be a specific phenomenon for nanotechnology since patenting activities over all technologies continued to increase during this period at the world level and also at the level of the United States (data not shown).

In the following chapter we will have a closer look at patenting activities in different nanotechnology subfields. This will also illustrate whether the observed time course for nanotechnology in total is also reflected in the different subfields or whether we can find differences between the subfields in terms of patenting dynamics.

Figure 3.2: Dynamics of nanotechnology patent applications in different world regions over the period 1997-2006

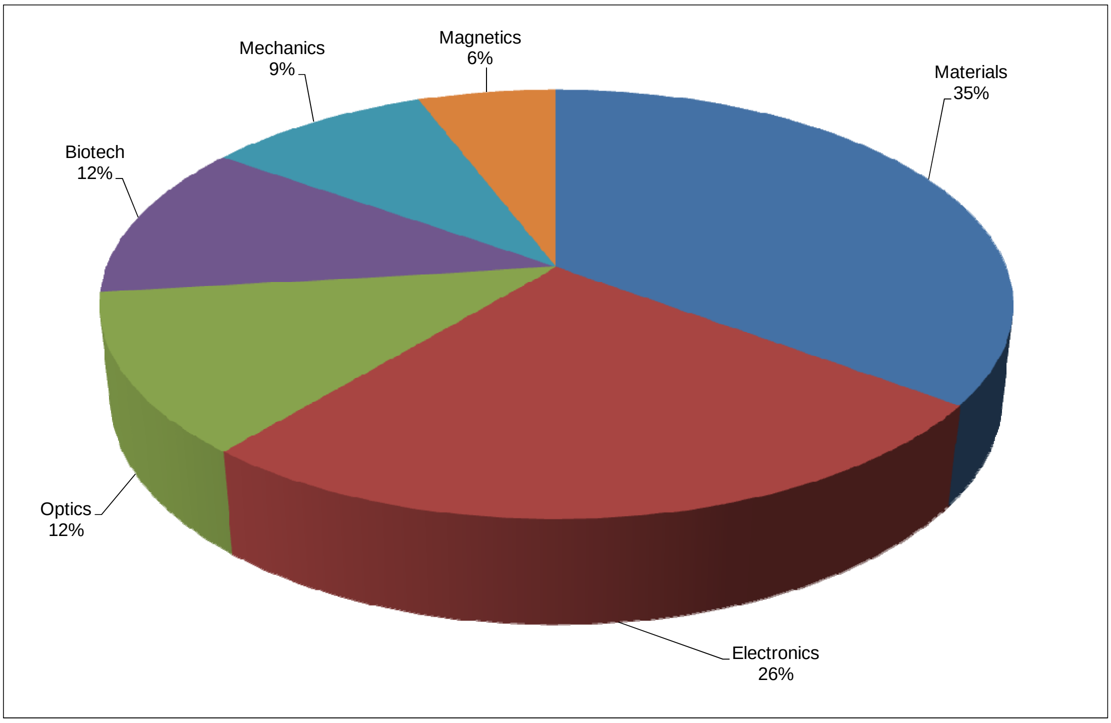


3.2 Comparing Russia and EU countries by nanotechnology fields

In the following we will analyse patenting activities of Russia and other world regions in different subfields of nanotechnology. For that purpose we differentiate nanotechnology into six subareas: nanomaterials, nanoelectronics, nanooptics, nanobiotech, nanomechanics, nanomagnetics. These fields have been defined by the EPO and cover different categories of the international patent classification (IPC). Accordingly they can be used for analysing subfield-specific patenting behaviour (see methodological annex).

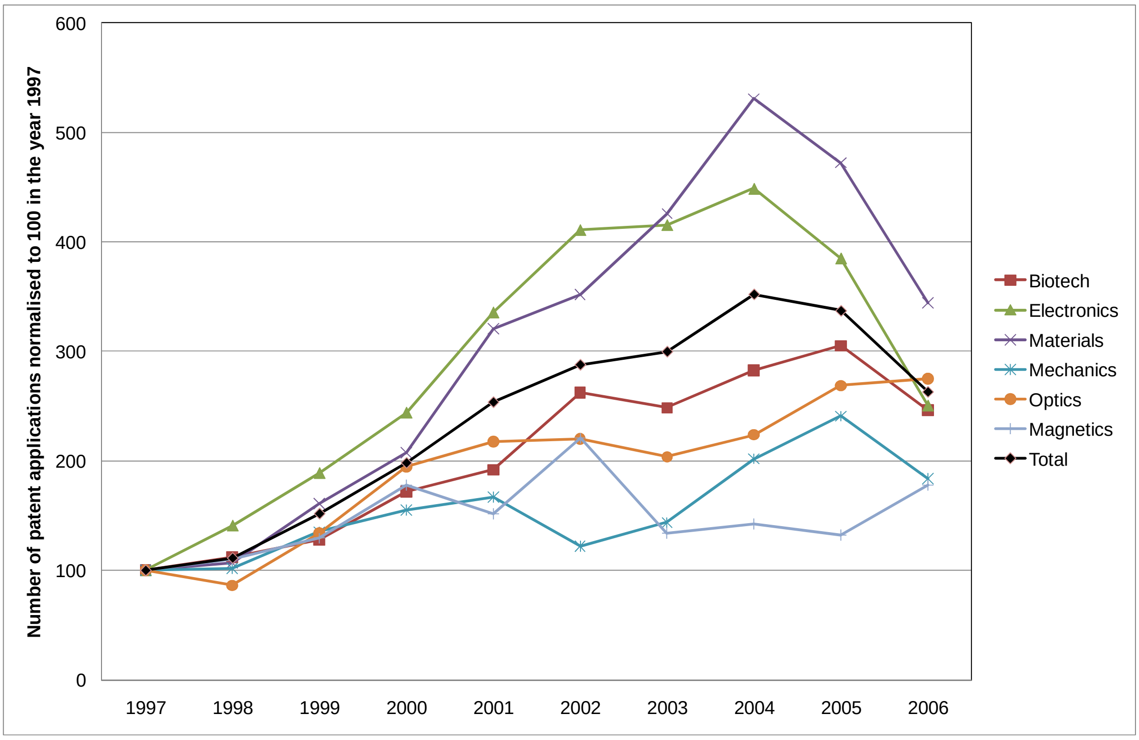
As shown in figure 3.3 nanomaterials comprises the largest of these subareas corresponding to 35 % of the 17.359 total nanotechnology patent applications worldwide over the period 1997 to 2006. Nanoelectronics with 26 % is another larger area. Nanooptics and nanobiotech each contribute 12 %, nanomechanics 9 % and nanomagnetics 6 % of the worldwide total nanotechnology patent applications.

Figure 3.3: Share of different nano fields in total worldwide patent applications over the period 1997-2006



For analysing how these six subfields developed over time, we measured time series for each subfield (figure 3.4). As already shown in the previous section the total field of nanotechnology grew continuously up to the year 2004 followed by a decrease until 2006. Two of the subfields, namely nanomaterials and nanoelectronics are characterised by a much stronger growth compared to total nanotechnology until the year 2004, but also exhibit a much steeper decrease between 2004 and 2006. Obviously, the overall pattern of the time course of nanotechnology is influenced strongly by these two fields which also are the two largest fields of nanotechnology patenting activities (see figure 3.3). Nanooptics and nanobiotech are two fields expressing continuous growth over the whole period except the last year, where nanobiotech also suffered from a certain decrease in patent applications. Obviously, the six subfields of nanotechnology developed rather differently during the last ten years. Such differences will be important when analysing in more detail suitable subareas for future cooperations between Russia and European countries during the following working steps of the NANORUCER project.

Figure 3.4: Patenting dynamics of nanotechnology subfields over the period 1997-2006 normalised to 100 in the year 1997



In the following patenting activities in the six nanosubfields will be compared between Russia and the EU15 over the period 1997-2006. As shown by figures 3.5 and 3.6 both countries have a focus on nanomaterials and nanoelectronics as indicated by patent application. In the case of Russia nanoelectronics seems to be even more important compared to the EU15. Concerning the smaller nano subfields, the strong focus of Russia on nanooptics is remarkable, while nanobiotech seems to be less important in Russia compared to Europe and also compared to worldwide patenting activities.

Figure 3.5: Patenting share of nano fields in Russia over the period 1997-2006

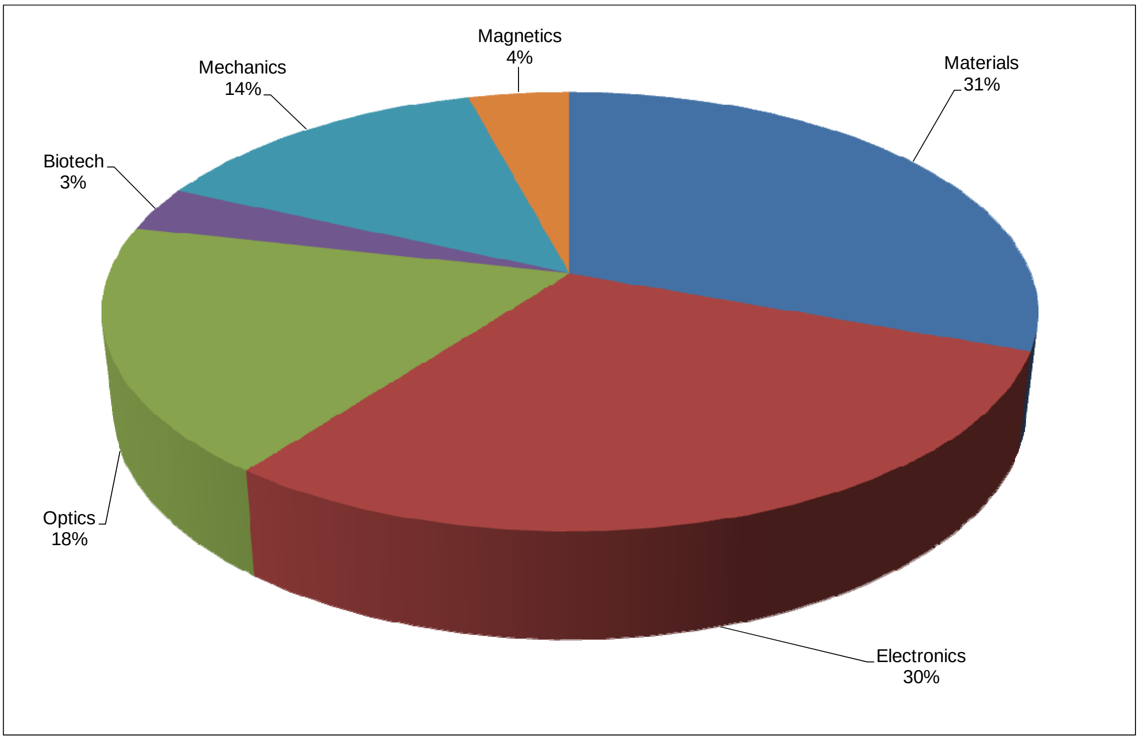
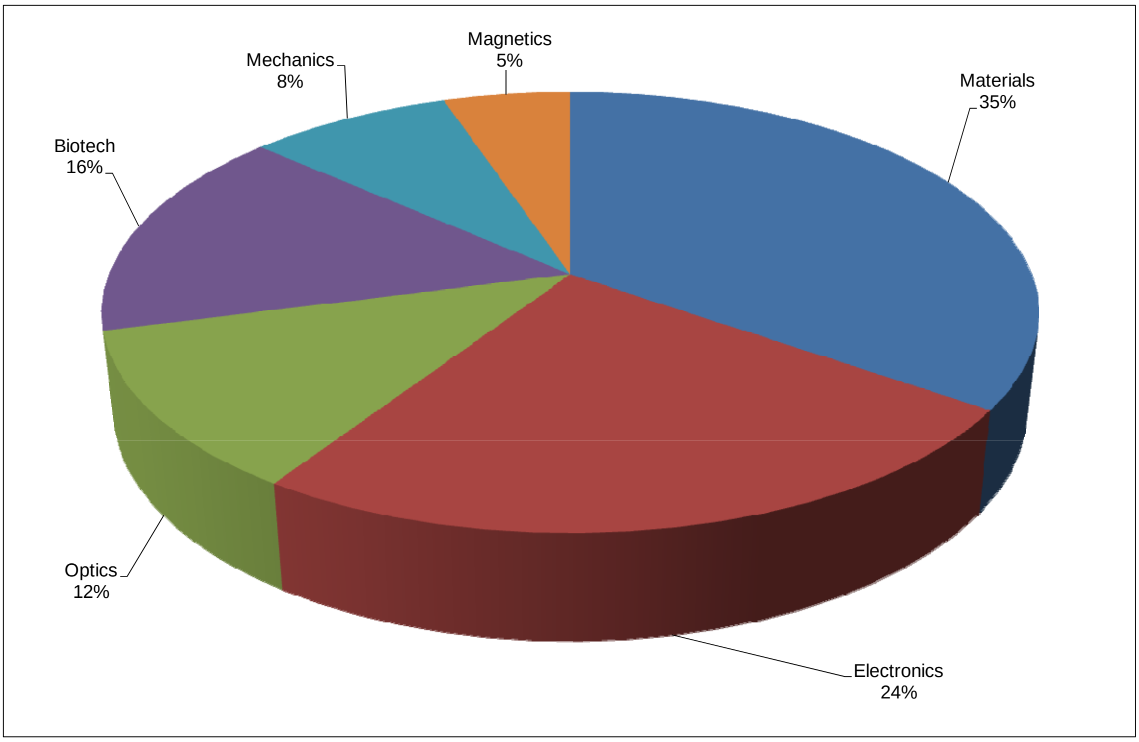


Figure 3.6: Patenting share of nano fields in EU15 over the period 1997-2006



As an additional background information for the identification of potential future topics for cooperation between Russia and European countries it is important to know to which extent individual European countries and Russia contribute to the worldwide patenting activities in nanotechnology as a whole and also in the six nanotechnology subfields. The results of these analyses are shown in figures 3.7 to 3.13. For total nanotechnology patent applications Germany takes a leading role contributing more than 10 % of all patent applications. With a share of 0.7 % Russia ranks at the ninth position (figure 3.7). The relatively best position of Russia within the six subfields can be observed in nanooptics (figure 3.12) and nanomechanics where Russia contributes more than 1 % of all patent applications, while, as already discussed above, nanobiotechnology is a subfield with only relatively low Russian patenting activities.

Figure 3.7: Share of different countries in worldwide nanotechnology patent applications over the period 1997-2006

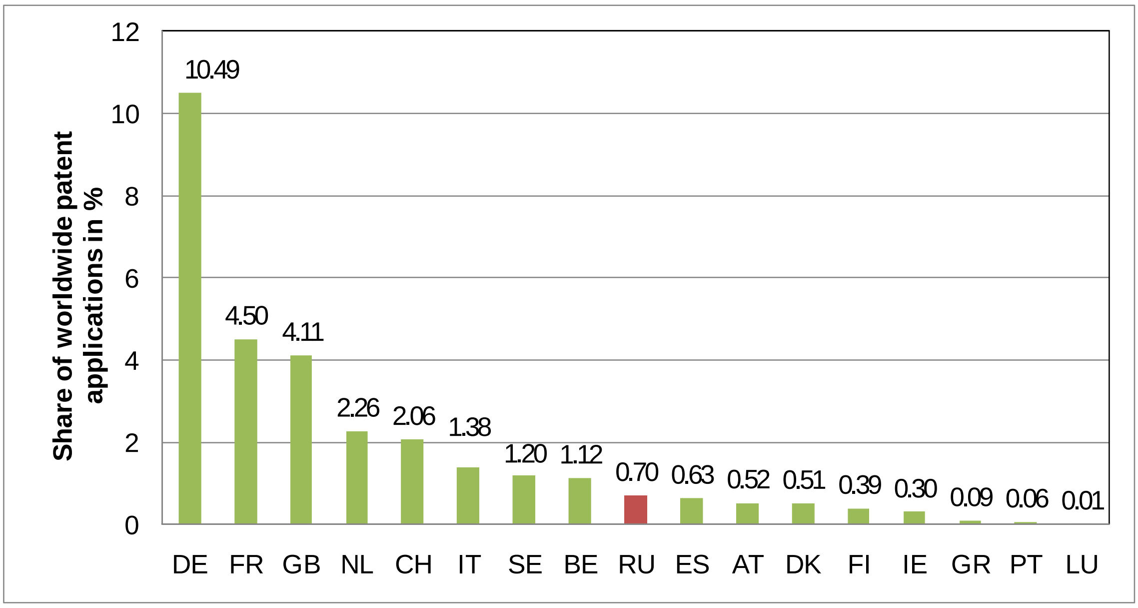


Figure 3.8: Share of different countries in worldwide patent applications in nanobiotechnology over the period 1997-2006

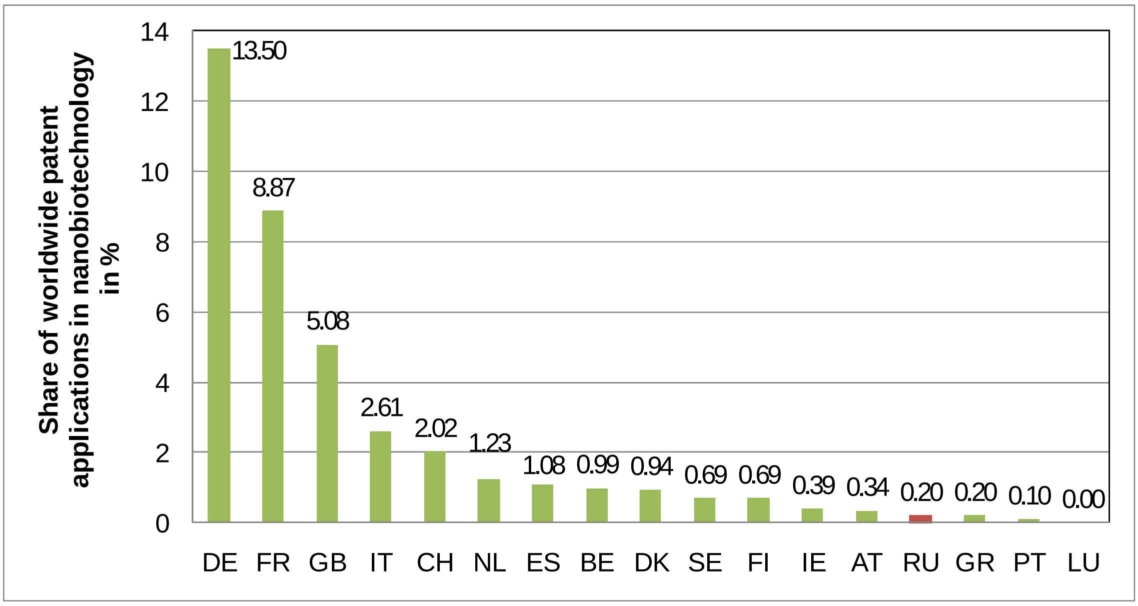


Figure 3.9: Share of different countries in worldwide patent applications in nanoelectronics over the period 1997-2006

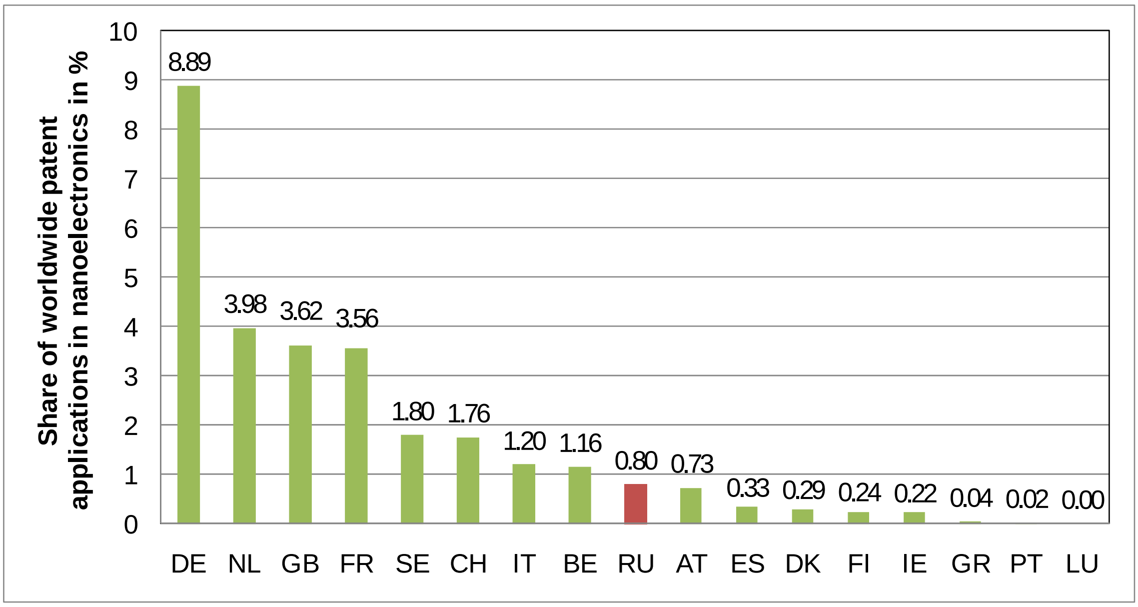


Figure 3.10: Share of different countries in worldwide patent applications in nanomaterials over the period 1997-2006

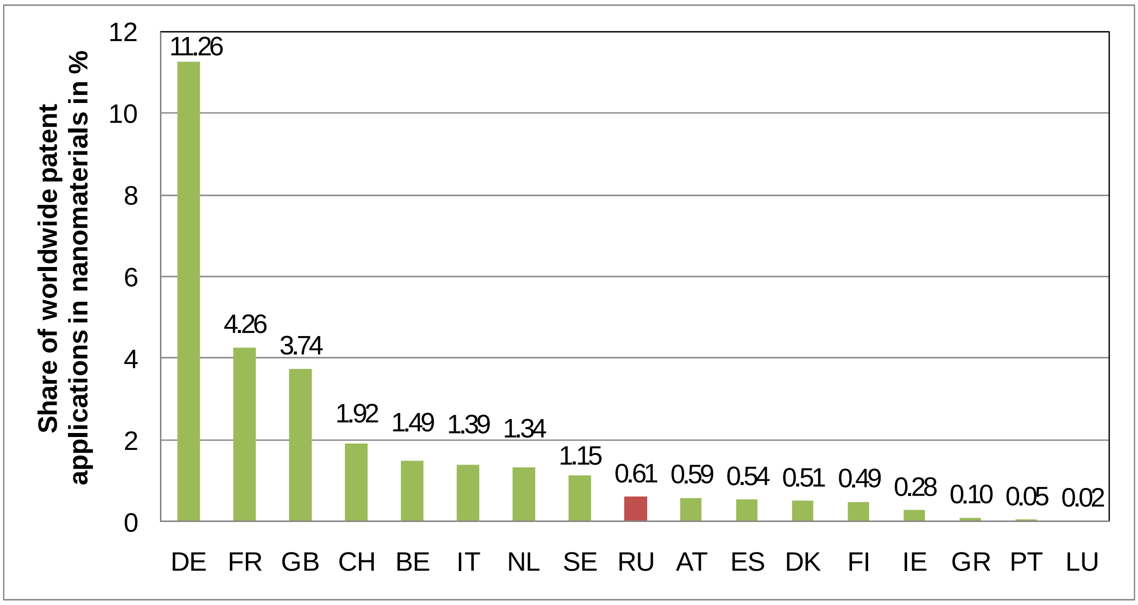


Figure 3.11: Share of different countries in worldwide patent applications in nanomechanics over the period 1997-2006

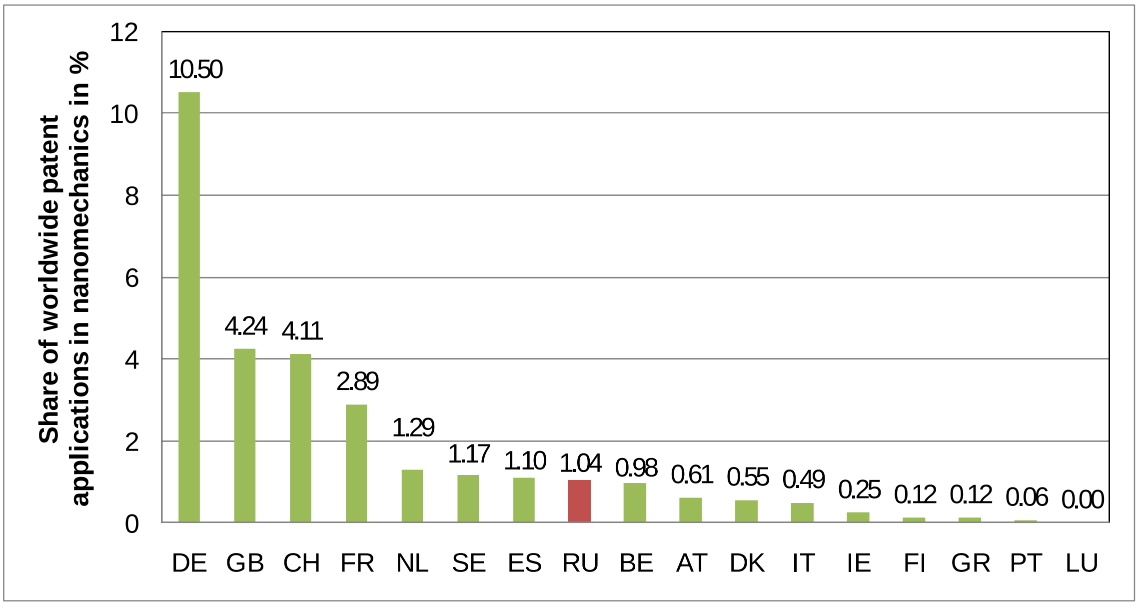


Figure 3.12: Share of different countries in worldwide patent applications in nanooptics over the period 1997-2006

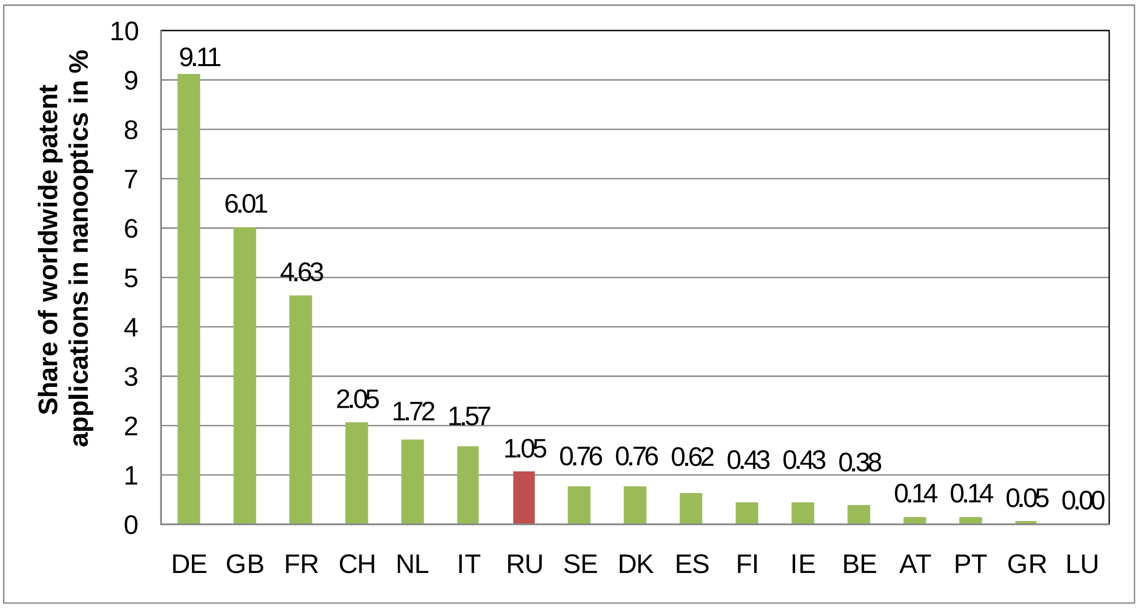
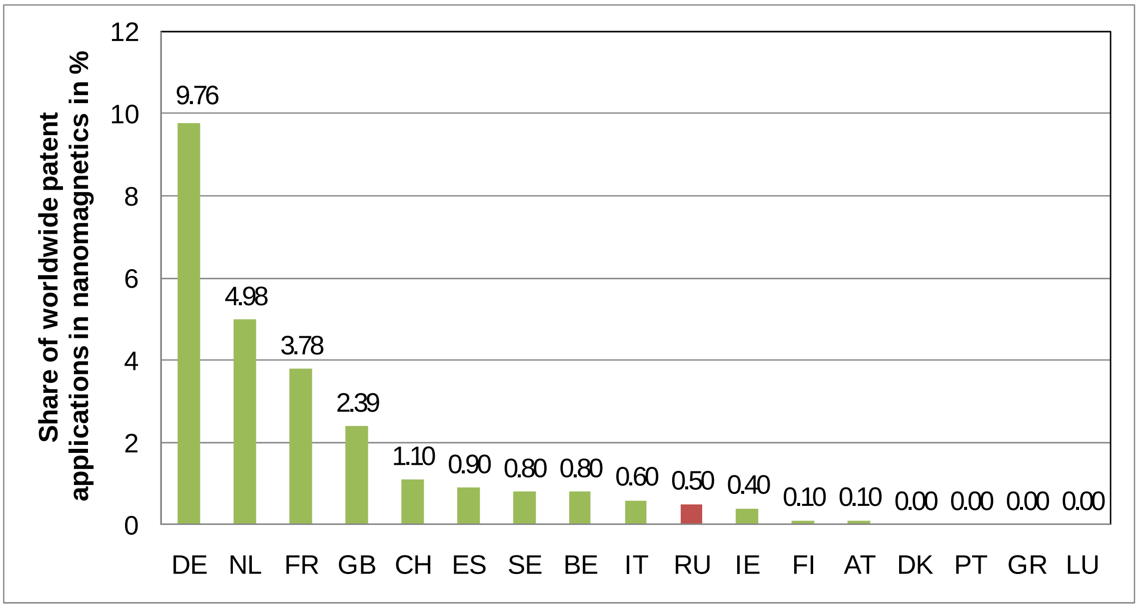


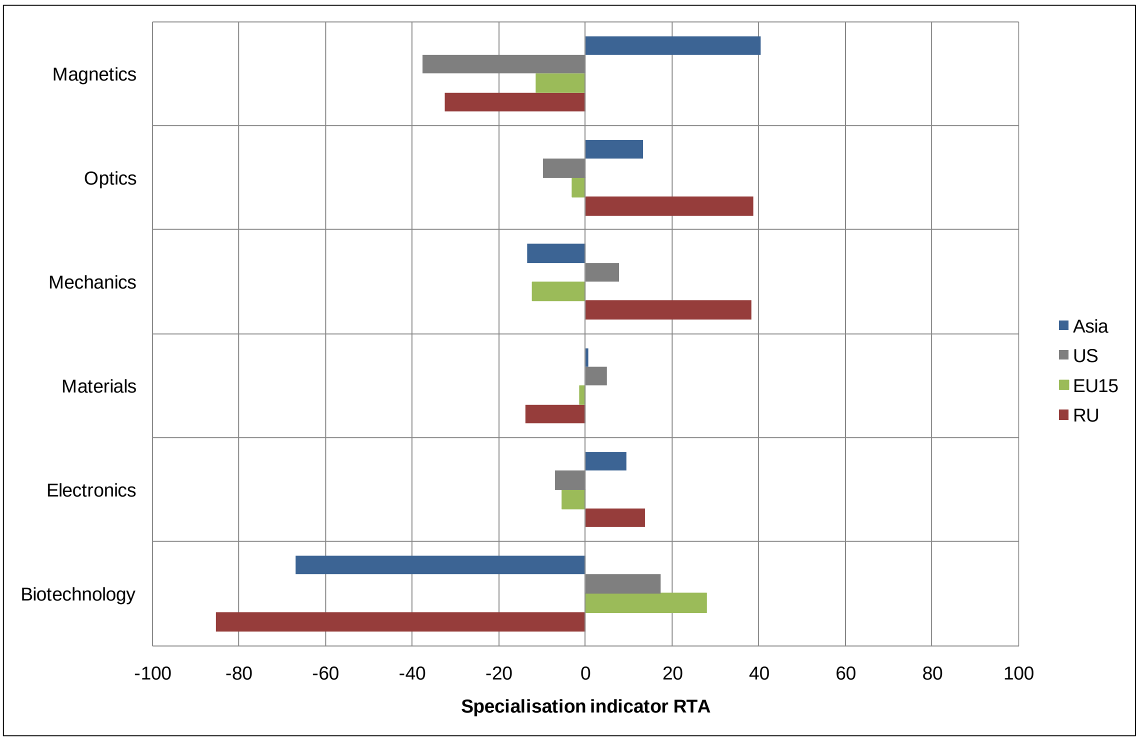
Figure 3.13: Share of different countries in worldwide patent applications in nanomagnetics over the period 1997-2006



3.3 Relative specialisation of Russia in nanotechnology fields

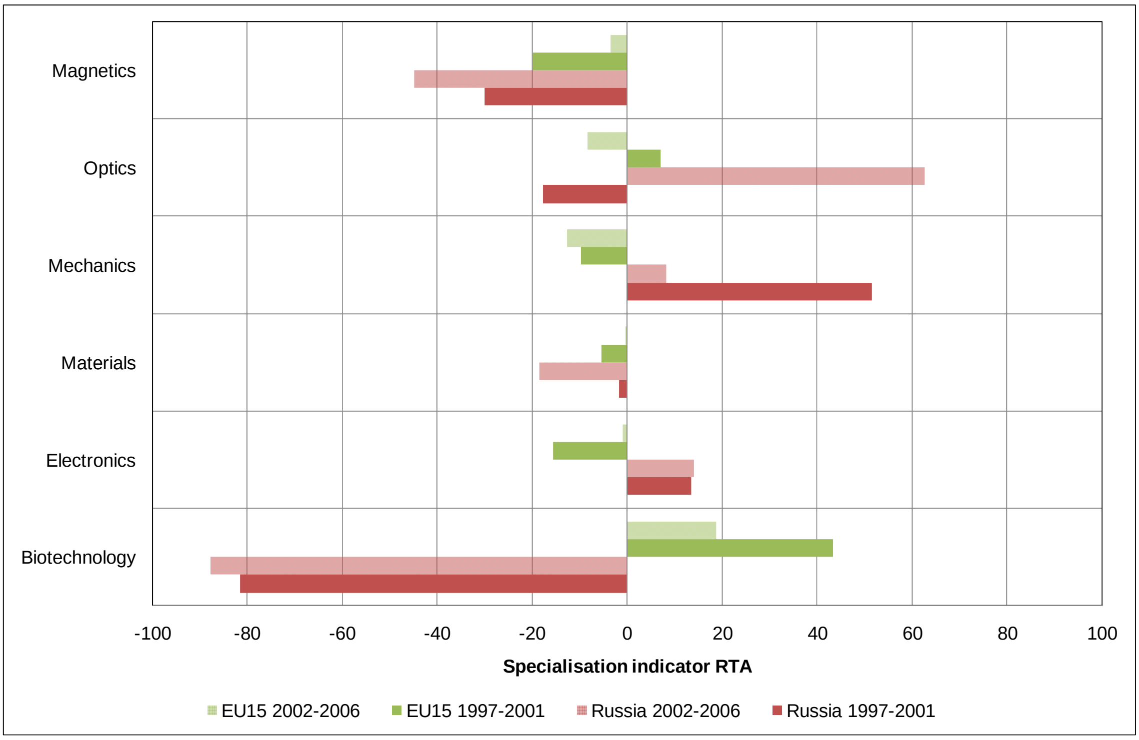
For a more detailed analysis of the relative specialisation of Russia in different nanotechnology fields we calculated the patent specialisation indicators in a similar way as already described for publications. As shown in figure 3.14 this analysis confirms the observations made above that Russia presents a clear specialisation in nanooptics and nanomechanics. None of the other three major regions considered is characterised by a similar specialisation pattern. Nanobiotechnology, on the other hand, is the subfield where Russia is not specialised in. Interestingly, the Asian countries express a similar underspecialisation in nanobiotechnology.

Figure 3.14: Relative specialisation of different world regions in nano subfields over the period 1997-2006



In order to detect potential changes in specialisation over the period considered, we also elaborated specialisation indices for two periods: 1997-2001 and 2002-2006 (figure 3.15). With respect to nanomagnetics, nanoelectronics and nanobiotechnology the specialisation pattern of Russia is rather stable over the ten-years-period. On the other hand, nanooptics and nanomechanics are subfields where we observe a pronounced shift in specialisation. In the case of nanooptics Russia turned from underspecialisation in the previous period to overspecialisation in the more recent period, while in the case of nanomechanics the opposite dynamics can be observed, Russia has become less specialised in the more recent period.

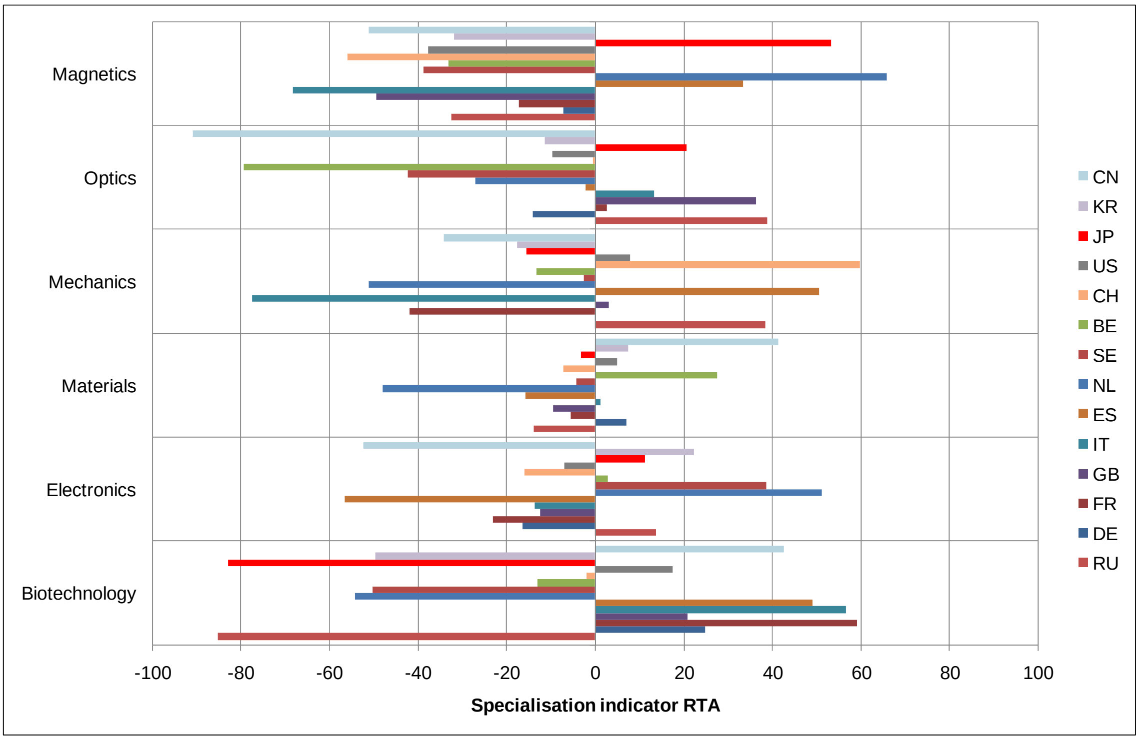
Figure 3.15: Relative specialisation in nano subfields for Russia and EU15 for two periods (1997-2001 and 2002-2006)



If we analyse in more detail relative specialisation in the six nano subfields on a country level, we can identify two groups of countries: those who present a similar specialisation behaviour as Russia in a certain field and those presenting opposite specialisation. Both cases could be interesting when considering potential cooperations. Opposite specialisation may provide opportunities for complementary activities, while similar specialisations may point to fields where strong forces could be joint thereby accelerating mutually the individual strengths.

For nanomagnetics, with the exception of Spain, the Netherlands and Japan, all countries considered present a similar underspecialisation as Russia (figure 3.16). In nanooptics only Great Britain, Japan and to a lesser extent Italy seem to be specialised as is the case for Russia. In nanomechanics Spain and Switzerland together with Russia present the strongest specialisation. In nanomaterials most countries including Russia seem not to be characterised by clear over- or underspecialisation. China and Belgium seem to be a bit more specialised, while the Netherlands tend to underspecialisation. In nanoelectronics we observe a more pronounced specialisation pattern with the Netherlands, Sweden, Korea and to a lesser extent Japan being more specialised as is the case for Russia. Finally, in the case of biotechnology there is a clearly opposite specialisation behaviour between Russia (underspecialisation) and the larger European countries, the United States and China (overspecialisation).

Figure 3.16: Relative specialisation in nano fields over the period 1997-2006 for Russia, EU15 countries, Switzerland, the USA, Japan, Korea and China



3.4 Summary of patent analyses

For analysing applied and market-oriented R&D activities we performed different patent analyses arguing that patent applications can be considered as suitable indicators for such activities. Worldwide patenting activities in nanotechnology increase considerably between 1997 and 2005 with a growth rate of about 3.5. However, towards 2006 a slight decrease of the number of patent applications on a worldwide level can be observed. This time course is largely influenced by the United States which contribute roughly one third of all worldwide patents in nanotechnology. The number of patent applications from the United States increased extraordinarily between 1997 and 2004. Obviously during this period very intensive invention activities in nanotechnology took place in the United States, indicating high expectations with respect to future commercial applications of nanotechnology. Since 2004 we observe a considerable drop in the number of patent applications from the United States. A comparison with other technology fields indicates that this dynamics is specific to nanotechnology. It needs to be seen, whether this trend will remain temporary or whether it will continue over the next years.

In order to identify the main regions contributing to worldwide nanotechnology patent applications, we analysed patent applications for nanotechnology as a whole but also for different subfields of nanotechnology at a country level. Besides the United States, which contribute roughly one third of all nanotechnology patent applications over the ten years period considered, European countries (EU15) and Asian countries are the other two main actors in nanotechnology patenting achieving a share of 26-28 % of all patent applications. For Russia we observe only a small share of 0.7 % of all patent applications. Compared to scientific capacities in Russia as indicated by scientific publications, where Russia obtained a share of 4 % of all worldwide publications, this low share in patenting activities indicates a rather low prospensity to patenting in Russia. During the field work to be carried out in work package 3 (surveys, interviews, workshops), we will explore in more detail the reasons for this patenting behaviour of Russia.

Nevertheless, even the comparatively small number of patent applications from Russia allows to perform specialisation analyses. These indicate a clear specialisation of Russia in the fields of nanooptics and nanomechanics, while nanobiotechnology is an area where Russia is underspecialised. The development over time of specialisation indicates that in the case of nanomechanics specialisation became less pronounced during recent years in Russia, while in the case of nanooptics specialisation strongly increased during the last years.

4 Conclusions

The analysis of scientific activities in nanotechnology using various types of publication counts as indicators revealed that Russia is an important player in the worldwide scientific nanotechnology community. We observe a clear specialisation of Russia in two subfields of nanotechnology, namely nanooptics and nanophysics. Also most larger European countries present a rather strong specialisation in these areas. Accordingly, we would expect a number of interesting opportunities for cooperation within these larger subfields. There are also two other areas where Russia presents lower intensities of scientific activities. These concern the intersection between nanotechnology and life sciences as defined by the scientific fields nanomedicine and nanobiotechnology. Since many European countries present a stronger specialisation in these two subareas, nanomedicine and nanobiotechnology might also be interesting fields where European countries and Russia could contribute complementary competencies for joint activities.

Thus, the analysis of scientific performance using bibliometric indicators gives some first ideas about potential nanotechnology subfields for future cooperation between Russia and European countries. In the following work packages of the NANORUCER project we will explore these potential fields in more detail. In particular the field work in Russia (survey of research institutions, interviews and workshops) to be carried out in work package 3 will provide additional detailed information in defining interesting topics for cooperation. Further bibliometric analysis will complement this work. In specific we will carry out an analysis of co-publications between Russia and European groups. This will provide additional information and potential topics and cooperation partners.

In order to analyse applied and market-oriented R&D activities, we investigated the patenting behaviour of various countries in nanotechnology. We observe only low numbers of international patents from Russia. We propose two different explanations for this situation: firstly, if we assume that publications reflect scientific activities and patent applications indicate activities concerned with applied research, technology transfer and commercialisation, we would conclude that nanotechnology activities in Russia are mainly focused on basic research, and applied research and commercialisation activities would play only a minor role.

Secondly, we could also assume that the low number of patents does not really reflect application- and commercialisation-oriented activities in Russia. Rather, it mainly would indicate a low prospensity to protecting inventions with international patents in Russia. This again would be due to lacking awareness of the role of patents, language biases, constraints in financing patent applications or other reasons.

Obviously, conclusions to be drawn for future policy support activities would be different for both cases. In the first case (low intensity of applied research and commercialisation activities), the task would be to support building up applied research and commercialisation capacities. In the second case (low prospensity to patenting), supporting activities should focus more on providing information and raising the awareness of the role and significance of patent protection, providing advice in legal issues related to patenting, and finally supporting patenting activities financially. During the field work of work package 3 we will explore in more detail the patenting behaviour of the Russian nanotechnology communities, so that we will be able to find out which of the two explanations would fit best.

Despite the low absolute numbers of patent applications from Russia, the patent analysis basically confirms the observations made already during the bibliometric analysis: Russia presents a specialisation in nanooptics, while life sciences applications of nanotechnologies are not a focus of Russian research activities.

The analysis of worldwide patenting trends in nanotechnology reveals a strong growth of patent applications since 1997 with a peak in 2004 followed by a drop-down towards 2005. In other technological fields we observe a typical so-called "double boom pattern" of the number of patent applications.[3] After an initial increase of patent applications to a first maximum the number of patent applications decreases thereafter. About 15 years after the first growth phase a second growth phase starts again, even exceeding the first maximum. The following interpretation has been put forward for such observations.[3] Shortly after the discovery of a new phenomenon an euphoric phase begins where a diverse range of application potentials, which can be realised rapidly, are described as immediately attainable. However, the problems involved in realisation are usually greater than expected, so that finally a reorientation phase follows, in which market contingencies play an increased role. This in turn results in a second dynamic development phase, a second boom, which is driven to a great extent by demand-pull factors and ultimately opens the way to prosperity and employment with the market launch of an innovation. It will be interesting to observe how the number of patent applications in nanotechnology will develop over the next few years in order to verify or falsify the described trends.

Looking at different subfields of nanotechnology reveals that the observed overall pattern does not describe adequately all subareas of nanotechnology. Rather, the overall pattern is mainly influenced by patent applications in nanomaterials and

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3 Schmoch, U. (2007): Double-boom cycles and the comeback of science-push and market-pull. In: Research Policy 36, pp. 1000-1015.

nanoelectronics, which also comprise the two largest subfields of nanotechnology contributing about 60 % of all nanotechnology patent applications.

5 Annex: Methodology

5.1 Annex A Publications

Typically, keyword-based approaches are used to define search strings for the delineation of nanotechnology (Hullmann and Meyer, 2003[4]), for both publications and patents. In 2008 Huang et al.[5] provided a comprehensive review of more than 120 social science studies in nanoscience and -technology, analysing particularly publication data. They found, that the keyword-based publication searches produce very similar ranking tables of the top ten nanotechnology subject areas and the top ten most prolific countries and institutions (among the analysed searches: Noyons et al. (2003)[6] and the search with prefix "nano").

The keyword-based search from Noyons et al. has been developed at Fraunhofer ISI and is among the best searches available to delineate the field of nanotechnology. The methodological approach of NANORUCER thus builds on this keyword based search.

In order to define suitable subfields of nanotechnology, the 172 subject categories[7] of the Science Citation Index (SCI) have been clustered into nine subfields:

1. nanophysics (comprising publications in applied physics, condensed matter physics, etc.),
2. nanochemistry (comprising publications in applied, physical, electro- etc. chemistry),
3. nanomaterials (comprising publications in materials and surface sciences),
4. nanooptics (comprising publications in optics, imaging, optical methods, e.g. spectroscopy, crystallography),
5. nanoengineering (comprising publications in fields such as engineering, instruments and instrumentation, mechanics, robotics, sensing, construction, etc.),

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4 Hullmann, A.; Meyer, M. (2003): Publications and patents in nanotechnology: an overview of previous studies and the state of the art. In: Scientometrics 58(3), pp. 507–527.

5 Huang C. et al. (2008): Nanotechnology Publications and Patents: A Review of Social Science Studies and Search Strategies. United Nations University. UNU-MERIT. Working Paper Series: #2008-058 (http://www.merit.unu.edu/publications/wppdf/2008/wp2008-058.pdf).

6 Noyons, E.; Buter, R.; Raan, A. van; Schmoch, U.; Heinze, T.; Hinze, S.; Rangnow, R (2003). Mapping excellence in science and technology across Europe: Nanoscience and nanotechnology. Report of Project EC-PPN CT-2002-0001 of the European Commission. Available at: studies.cwts.nl/projects/ec-coe/downloads/Final_report_13112003_nano.pdf, last accessed on February 18, 2010.

7 http://science.thomsonreuters.com/cgi-bin/jrnlst/jlsubcatg.cgi?PC=K

6. nanobiotechnology (comprising publications in fields such as biology, biophysics, biochemistry, molecular biology, etc. and further fields of life sciences),
7. nanomedicine (comprising publications in all fields of medical applications),
8. nanomodelling (comprising publications on computational and mathematical methods),
9. nanomultidisciplinary (comprising cross- and multi-disciplinary publications in nanotechnology with no clear allocation to one of the fields 1 to 8).

The analysis of nanotechnology fields has been done using the Science Citation Index (SCI) via the host STN. The searches have been conducted for the ten year timeframe between 2000 and 2009.

A comparison between countries like the EU15 Member States, the USA and Asian countries (Japan, China, Taiwan, Korea, India, Singapore) and Russia was straight forward to do. We focused on the EU15 Member States (for publications and patents), since the EU15 already account for more than 90 % of the publication activities compared to the EU27. Thus, publication patterns in nanotechnology and subfields are expected not to deviate too much. Also, on basis of individual Member States, the further 12 EU countries do not show significant activities in the field. Instead, we decided to include Switzerland as additional country with relevant activities in nanotechnology.

For our analyses on publication activities we avoided to consider absolute numbers of publications but rather put the activities of countries and regions in nanotechnology and subfields into relation, e. g. relative share (in percent), normalised to a basis year, etc.

An index, that helps to avoid analysing absolute publication numbers, is the Revealed Publication Advantage (see also RTA in Annex B Patents) and has been used for analyses in the present performance analysis. The index is defined as follows:

$$RPA_{ij} = 100 * \tanh\left\{ ln\left(P_{ij} \Big/ \sum_i P_{ij} \right) \Big/ \left(\sum_j P_{ij} \Big/ \sum_{ij} P_{ij} \right) \right\}$$

where

P_{ij} = number of publications of a country i in a field j,

$\sum_i P_{ij}$ = number of publications of all countries in a field j,

$\sum_j P_{ij}$ = number of publications of a country i in all fields, and

$\sum_{ij} P_{ij}$ = number of publications of all countries in all fields.

The RPA index is used to determine specialisation profiles of countries in concrete technology fields. For an interpretation of the RPA see the explanations in annex B.

5.2 Annex B Patents

The European Patent Office (EPO) introduced a number of tags to label the nanotechnology field in the EPO databases[8]. When a document containing nanotechnology is added to the databases, the EPO assigns a "Y01N" tag, so that it can be easily located in a search. The EPO constantly updates and improves the Y01N code as new aspects of nanotechnology emerge. Y01N is divided into six main groups with each group collecting nanotechnology patents of similar technological backgrounds:

1. nanobiotechnology (Y01N2),
2. nanotechnology for information processing, storage and transmission (Y01N4), abbreviated as nanoelectronics,
3. nanotechnology for materials and surface science (Y01N6), abbreviated as nanomaterials,
4. nanotechnology for interacting, sensing or actuating (Y01N8), abbreviated as nanomechanics,
5. nanooptics (Y01N10),
6. nanomagnetics (Y01N12).

Exemplary technologies to the six main groups can be found in OECD 2009 or Scheu et al. 2006 (see table 1).[9] The EPO has tagged about 86,000 patent documents from around the world with one of the six Y01N tags.

For the analysis of nanotechnology activities in terms of patent applications, the relevant documents have been extracted using the PATSTAT database[10]. Two times per year, in April and September, the EPO provides an update to the nanotechnology patents, which is transferred at Fraunhofer ISI to an in-house database for conducting

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8 European Patent Office (EPO), Nanotechnology in European Patents – Challenge and Opportunity: A New Way of Searching Nanotechnology in EPO Databases, http://www.epo.org/topics/issues/nanotechnology.html.

9 Scheu, M. et al. (2006): Mapping nanotechnology patents: The EPO approach. In: World Patent Information 28 (2006), pp. 204–211.

10 PATSTAT is the EPO Worldwide Patent Statistical Database developed and maintained by the EPO for government and intergovernment organisation as well as academic institutions. PATSTAT covers the patent data of about 70 national and international patent offices. Access to the database is not available to the public. *See e.g.*, EPO, Frequently Asked Questions: Where Can I find Patent Statistics? http://www.epo.org/help/faq.html.

analyses of the field and the six subfields. The searches have been conducted in the ten year timeframe between 1997 and 2006. More actual data, i. e. data on patent applications for 2007, will be available in autumn 2010.

Table 1: Exemplary technologies

EPO nanotechnology tagging codes in subclass Y01N

Code	Title	Exemplary technologies
Y01N2	Nanobiotechnology	• Nanocapsules as carrier systems for therapy and pharmaceutical treatment • Biomolecular motors • Molecular arrangements for biocatalysts • Pre-targeting with peptides or antibodies • Host-guest complexes in targeted drugs • Ultrasound imaging or radioactive pharmaceutical preparations
Y01N4	Nanotechnology for information processing, storage and transmission	• DNA computing • Quantum computing • Single electron logic • Nanotube displays • Biomolecules for electronics and data storage • Read heads with nm precision
Y01N6	Nanotechnology for materials and surface science	• Nanoparticles, nanocomposites, dendrimers, nanotubes and fullerenes • Supramolecular systems • Ultrathin functional films • Self assembling monolayers (SAM) • Hydrogen storage in nanostructured materials
Y01N8	Nanotechnology for interacting, sensing or actuating	• Measurement of physical, chemical, biological properties at surfaces with nm-resolution • Measurement of interfaces with lateral resolutions in the nm-range • Normalisation routines for nanoanalytics • Measurements of size distribution of nanoparticles • Tools for ultraprecision engineering like Scanning Probe Microscopes • Use of quantum dot labels for analysing biological material
Y01N10	Nanooptics	• Optical quantum well structures • Photonic crystals • Quantum optics • Optical surfaces with nm surface precision
Y01N12	Nanomagnetics	• Low dimensional magnetism • XMR technologies such as magnetoimpedance, anisotropic magnetoresistance, giant magnetoresistance, tunnelling magnetoresistance

Source: Scheu et al. 2006

In order to compare the patent activities of the EU15 Member States, the USA and Asian countries (Japan, China, Taiwan, Korea, India, Singapore) and Russia transnational patents have been considered, i. e. no patent applications at national patent offices have been considered, which would imply a domestic bias. Transnational patents are patent families with at least one EPO or one PCT application.

The European Patent Office (EPO) is a regional office and in consequence all application countries are foreign. It came into being in 1978 after the European Patent Convention was signed. In 2008, 32 countries have been Member States of the European Patent Organisation and another five countries were associated. The EPO is not an institution of the European Union and some of the Member Countries do not even belong to the EU, for example Switzerland. For patent protection in more than one country, only one central examination and granting process must be passed. However, at the end of this process at the EPO, a transfer to the final countries of designation is necessary and patent protection is still national. This specific structure at the EPO implies a more balanced relation between countries of origin.

In parallel to the start of the EPO in 1978, international applications according to the Patent Cooperation Treaty (PCT) were introduced. PCT applications are administered by the World Intellectual Property Organisation (WIPO), but the applications are filed at national offices of the 138 contracting states or the EPO7. The advantage here is that a patent procedure can be started in many countries without the direct need of translation. Some selected offices conduct international searches and - if required - preliminary examinations which can be used for information, but which are not legally binding. So in contrast to the EPO, the PCT process implies primarily a central application without final grant. The PCT process ends with a transfer to selected national or regional offices.

The analysis of transnational patent applications thus enables a reasonable comparison of countries, which would not be possible when searching at national patent offices only. On the other hand, the number of patent applications identified in this way is likely to be smaller than the real or absolute number of applications worldwide. Therefore, the absolute numbers of patent applications should not be overestimated and always be set into relation to a reference system, e. g. relative share (in percent), normalised to a basis year, etc.

An index, also avoiding to analyse absolute numbers of patent applications, is the so-called Revealed Technological Advantage (RTA) often used to compare patent activities of countries in specific fields. The index has been suggested by Soete and Wyatt (1983)[11] and is defined in the following way:

$$RTA_{ij} = 100 * \tanh\left\{ \ln\left[\left(P_{ij} \Big/ \sum_i P_{ij}\right) \Big/ \left(\sum_j P_{ij} \Big/ \sum_{ij} P_{ij}\right)\right]\right\}$$

where

P_{ij} = number of patents of a country i in a field j,

$\sum_i P_{ij}$ = number of patents of all countries in a field j,

$\sum_j P_{ij}$ = number of patents of a country i in all fields, and

$\sum_{ij} P_{ij}$ = number of patents of all countries in all fields.

11 Soete, L. G.; Wyatt, S. M. E. (1983): The use of foreign patenting as an internationally comparable science and technology output indicator. In: Scientometrics, 5, pp. 31–54.

The RTA index is generally used to determine specialisation profiles of countries in concrete technology fields and has been studied for patents and publications here.

The term in the inner brackets may have values between 0 and infinity. A value of 1 means, that country i behaves in field j the same as all countries in all fields. The logarithm is used to achieve a neutral value of 0 and a linearisation around 0 and the hyperbolic tangens for introducing upper and lower limits of 1 and -1, respectively. Thus, the RTA as defined here may have values between -100 and +100, pointing to negative or positive specialisations of a country i in a field j.