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Perspectives in Nanotechnology Based Innovative Applications For The Environment

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In this perspective paper, the actual trends in nanotechnology based innovative applications for the environment are analyzed and possible future trends were studied.
On the basis of the relevant topics of the NINE congress held in Rome, 2016, a bibliographical search was performed on papers fitting in one or more categories within the last 5 years, that is:
1. Nanosensors and bionanosensors for environmental characterization and monitoring
2. Technologies for the production of Nanomaterials for the environment
3. Nanostructured materials for advanced remediation processes
4. Nano-based water and wastewater treatment processes
5. Membrane processes for the environment
6. Health and safety issues concerning Nanomaterials
7. Education on Environmental Engineering and Nanotechnology.

A yearly count of contributions was performed and taken as an indicator of interest of the specific topic within the wide broad scientific community.
In a second step, the resulting data was analyzed by regression techniques to estimate the trend in the next future and to evaluate the next challenges within the international research framework.

1. Introduction

Nanotechnology represents the ''key technology'' of the 21st century and the expectancy for innovations in the environmental sector is significantly high. The word Nanotechnology includes a wide range of technologies performed on a nanometer scale for widespread applications. The main difference between a nano-material and a larger-scale-material is the significantly larger specific surface area which grants an increase in the chemical reactivity and/or a change to the physical properties of the material (Yang et al., 2013). The new properties showed by this new class of materials have already been used in the manufacture industry for decades; the large and rapid increase of applications of nanotechnology is due to the convergence of scientific disciplines as chemistry, physics, biology and engineering (Liu et al., 2012). Subsequently several nano-materials were introduced in medicine , in biotechnology, in computer science, in space exploration, in chemical industry. Nanotechnology innovative materials and processes have already contributed to the development of chemical industry through new nano-catalyzers and products (Yu et al., 2010). As regards the environmental sector remarkable studies were done by several researchers about saving raw materials, wastewater and contaminated soil treatment, energy storage and hazardous waste management (Wang and Dai, 2013; Meridian Institute, 2006). The OECD suggests that nanotechnology can contribute to solve different environmental issues as the provision of clean drinking water and the transformation and detoxification of a wide range of contaminants like PCBs, heavy metals, organochlorine pesticides and solvents (OECD, 2005). Nano-materials show environmentally interesting chemical and physical properties that make them suitable for several applications in a wide field as the environmental one (Satapanajaru et al., 2008). Examples comprehend the increased durability of materials against mechanical stress or weathering (Campillo et al., 2008), the high specific surface area and chemical reactivity of nano-particles used for wastewater and contaminated soil treatment (Ochando-Pulido et al., 2014) or based on nanofiltration processes (Stoller et al., 2014), or even a combination of the latter two (Stoller, 2013), the large absorption cross section of particular nanocages used as efficient and environmental-friendly contrast agents for optical imaging (Chen et al., 2005). The possible research directions as well as up-scaling processes are almost immeasurable. The aim of this work is to evaluate the weight of the environmental field inside the wide nanotechnology field. The bibliometric research represents the most suitable mean to identify and study related informative documents about the environmental sector; different quantitative indicators on temporal trends were adopted to show the latest technology-driven nano-material research trends (Menèndez-Manjòn et al., 2011). The current stream in nanotechnology research applied to the environmental sector is mapped by a bibliometric approach retrieved from the Science Citation Index.

2. Method

A search procedure was set analyzing different works present in literature to have an overview of nanotechnology applications in environmental sector. First of all two different search query in Scopus were generated in the time range between 2005 and 2015; in the former documents which presented the word ‘’nanotechnology’’ in the abstract, in the title or in the text, were selected and a refinement procedure was carried out. Among the several papers found only those which were relevant in chemical engineering and faithfully studied were selected. Subsequently a second search query was generated in Scopus in the same period of time, using the keyword ‘’environment’’. The same refinement procedure was done. Furthermore the intersection of the nanotechnology data set and the environment data set was used to generate a data pool of papers on nano-environment field. This data were elaborated and the 10 most cited articles in the last 10 years were collected. As it is possible to observe from the Table 1, there was a remarkable growth of interest in nano-environment field in the last 10 years. Furthermore, starting from the peak year of each field, the three data sets were analyzed to evaluate the publication activity trend in these fields. Another research was generated to evaluate three areas of environmental study: water, air and soil.
The goal of this work is to map the influence and the use of nanotechnology in environmental sector and its impact in scientific research topics.

3. Results and Discussion

The analysis of articles presented in literature allowed to create a growth curve of work numbers in the time range between 2005 and 2015. In figure 1 it is possible to observe that the number of papers has increased steadily and this confirms also the gain of interest about this field.

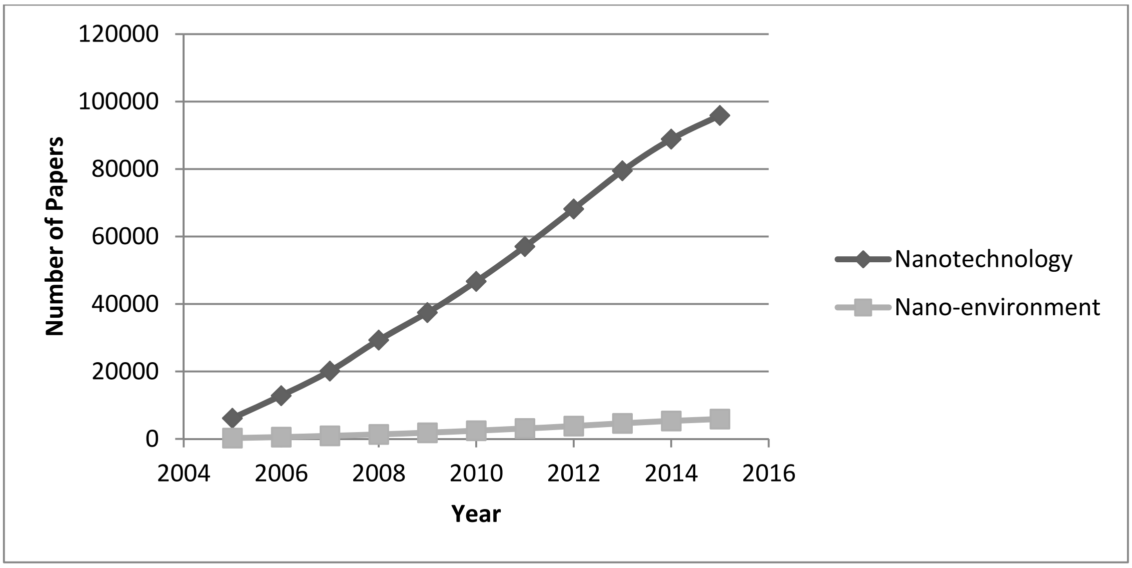

Figure 1: Growth curve of number of Papers in a range time from 2005 to 2015.

As expected the research activity in the examined fields increased between 2005-2015 and the curves show an exponential growth in each sector. Figure 2 showed that 2013 and 2014 were the years in which the research activity was more significant (more than 130000 papers were published in both years).

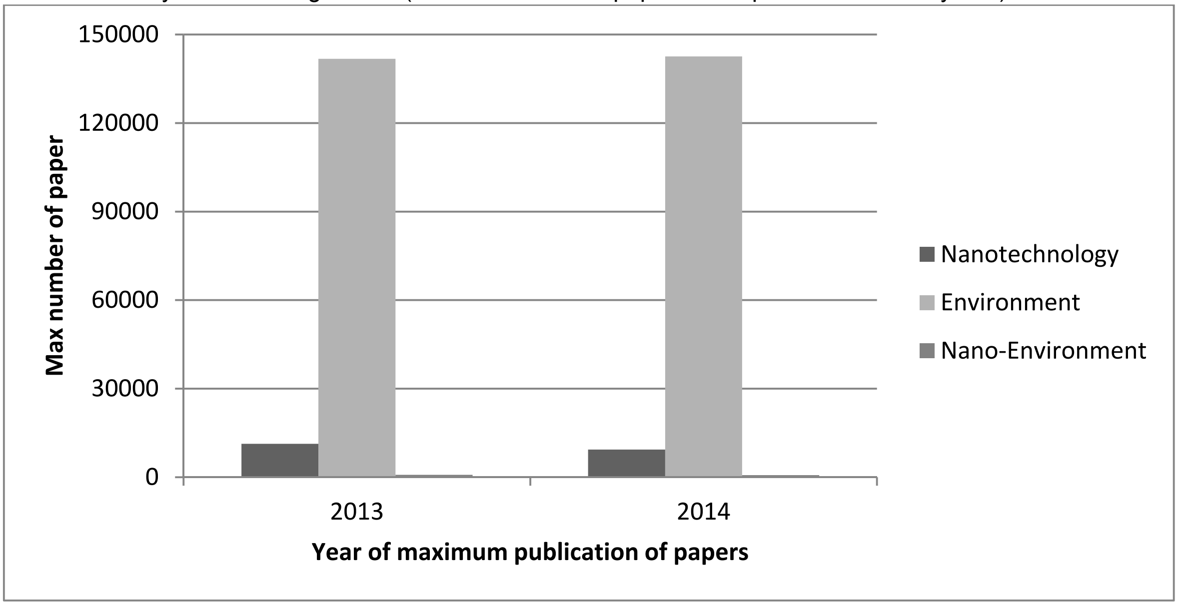

Figure 2: Comparison between the number of papers in environment, in nano-technology and nano-environment in two pick years (2013- 2014).

As showed in Figure 2 the number of records dealing with the environmental sector is one order of magnitude larger than for nanotechnology and two orders of magnitude larger than for nano-environment. This difference is due mainly to the wide range of applications in the environmental sector, to the remarkable number of authors in this sector and to the fact that the nano-environment filed is a recent area of research. The 10 most cited article of the nano-environment data set are reported in Table 1.

Table 1: The 10 most citied nano-environmental articles from 2005 to 2015.

	Citations
Toxic Potential of Materials at the Nanolevel. Nel, Xia, Madler, Li. Science (www.sciencemag.org) 311, 622- 627 (2006)	3665
Understanding biophysicochemical interactions at the nano–bio interface. Nel et al. Nat. Mater. 543- 547. (2009)	1880
Recent Advances in Sensitized Mesoscopic Solar Cells. Gratzel. 1788- 1798 24, 11. (2009)	1338
Exploring and Engineering the Cell Surface Interface. Molly M. Stevens and Julian H. George. Science (www.sciencemag.org) 310, 1135-1138 (2005)	1237
Direct-Current Nanogenerator Driven by Ultrasonic Waves. Wang X., Song, liu, Lin Wang. Science (www.sciencemag.org) 316, 102- 105 (2007)	1198
On the Controllable Soft-Templating Approach to Mesoporous Silicates. Wan and Zhao. Chem Rev. 107, 7. (2007)	1170
Fast Mass Transport Through Sub–2-Nanometer Carbon Nanotubes. Holt et al., Science (www.sciencemag.org) 312, 1034- 1037 (2006)	1085
Exploring and Engineering the Cell Surface Interface. Stevens and George. Science (www.sciencemag.org) 310, 1135- 1138 (2005)	1072
A Toxicologic Review of Quantum Dots: Toxicity Depends on Physicochemical and Environmental Factors Rod Hardman Environmental Health Perspectives; 114- 2 (2006)	1041
Nanomaterials in the environment: Behaviour, fate, bioavailability and effects. Klaine Stephen J. et al. Environmental Toxicology and Chemistry; 27- 9; (2008)	956

The search query was led to the analysis of the three wide fields of interest of the environmental sector: the preservation and remediation of air, water and soil. Figure 3 shows the trend of this research topics during the 2005-2015 time period. As shown in the figure the topic of most interest is the wastewater treatment, in particular the application of nano zero-valent iron (nZVI), magnetite (Fe_3O_4) and maghemite (γ- Fe_2O_3) in the wastewater and groundwater remediation represents the most studied topic (Tang e al., 2013). The other significant topic in the environmental sector is the use of pocket-size sensors for the detection and monitoring of pollutants present at the workplace.

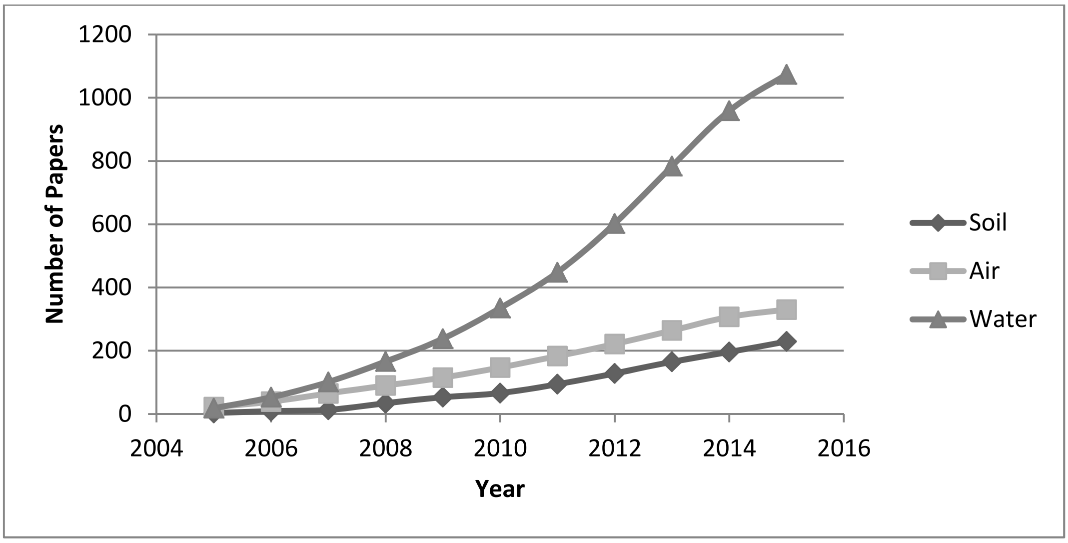

Figure 3: Annual growth rate of the number of publications in the 2005-2015 time period.

Figure 4 shows the remarkable interest in the wastewater and groundwater treatment sector, related to the other two fields. As it possible to observe this field of research has the 65.77 % of the total number of publications in the environmental sector, while the air and soil sectors have the 21.20 % and 14.02 %, respectively.

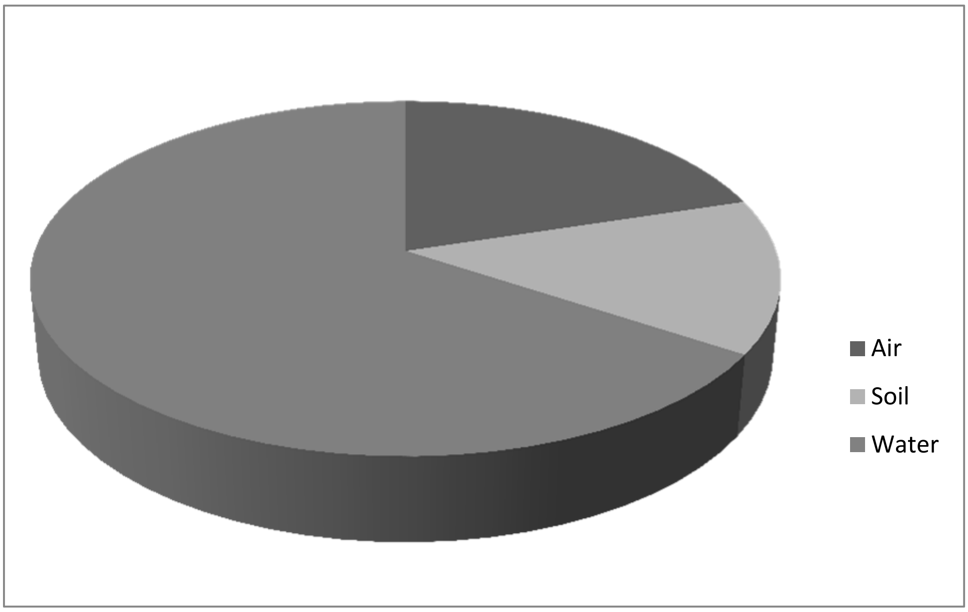

Figure 4: Pie chart of the application of nano-environment in the air (21.20 %), soil (14.02%) and water (65.77 %) sectors.

4. Conclusions

The field of nanotechnology is becoming increasingly popular in recent times in scientific and technological research. The influence in the various fields of research can be estimated by drawing up an analysis of work in the literature on the use of nano-engineered systems. In this review, an analysis was conducted on the use of nanotechnology in environmental treatment, considering the interest of those in more specific areas such as water, air and soil. It has emerged as the interest in these new remediation technologies has increased in the last 10 years, even if the traditional processes (chemical and biochemical) are still the most used. Water treatment is the topic that reports the highest number of publications (65.77 % of the total number of publications in the nano-environment field). In particular this growing interest is due to the peculiar properties of the nanoparticles used as high surface-area and related chemical activity, high mobility and peculiar magnetic and mechanical properties.

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