Opportunities for Joint Cooperation in R&D for FEALAC Countries: On Nanotechnology and Biotechnology

Iván Montenegro Trujillo*, Edgar E González Jiménez, & Mónica Botero Ospina*****

Abstract

The general purpose of this paper is to identify opportunities for and to measure existing collaboration on research and development between institutions from the countries of Asia and Latin America in FEALAC's framework, in the fields of biotechnology and nanotechnology and their convergence. The methodological approach includes scientific and technological surveillance and research seeking to identify both the R&D and innovation capacities of the countries as well as the degree of international cooperation between countries of the two regions; case studies and a study of the governance framework of international collaboration in R&D about issues considered global challenges. The study has three main findings. First, nanotechnology, biotechnology and their convergence contribute to solving the problem of contamination by heavy metals affecting most of the countries that are part of FEALAC and to address problems arising from the accelerated rate of energy consumption, which also contributes to environmental damage. In this scenario, important business opportunities arise from the adaptation and development of bio-refinery technologies. Second, the scientific relationship between FEALAC countries, mainly between Asian and Latin American countries, is weak as can be seen in research for articles and patents. But there is plenty of room and potential for improvement. Third, current and upcoming joint R&D programs and projects should be linked both to existing governance structures and to new ones that serve as experiments of STI public policy regarding innovative management of intellectual property and capacity building. Practical implications are included in lessons learned and a set of recommendations involving a couple of proposals. One proposal calls for research and innovation in promising fields for international cooperation. Another proposal creates mechanisms in the governance framework for sharing knowledge, capacity building, and funding.

Keywords
nanotechnology, biotechnology, technological intelligence, FEALAC

* Corresponding author, Senior Advisor, STI Policy Unit, Colciencias, Bogotá D.C., Colombia, imontenegrotrujillo@gmail.com
** FEALAC–Cbionano Coordinator; Associate Professor, Pontificia Universidad Javeriana; PI Nanoscale Science and Technology Center, Bogotá D.C., Colombia, egonzale@javeriana.edu.co
*** Advisor, Colciencias, Bogotá D.C., Colombia, mmboteroo@gmail.com

1. INTRODUCTION

The degree of R&D collaboration among Asian and Latin American countries is very low, which may imply postponed or missed opportunities to help overcome common pressing environmental problems. Examples include contamination by heavy metals especially in water resources and problems arising from the accelerated rate of energy consumption, which also contributes to environmental damage. Without strong R&D collaboration, actors may also lose out on important business opportunities. Nevertheless, there are some subsets of sub-regional collaboration clusters in Asian and in Latin American countries in the fields of nanotechnology and biotechnology R&D that we analyze later.

Nanotechnology, biotechnology, and their convergence can be applied to common environmental problems that affect most FEALAC[1] countries. One is contamination by heavy metals (e.g., mercury, cadmium and arsenic). Another are those related to energy consumption. Overall, energy and environmental crises are among the main challenges that must be overcome in the 21st century. Moreover, climate change imposes new demands on the management of water and energy resources, which are closely linked to food security, public health, and socioeconomic welfare. In the fields of nanotechnology and energy, the thematic networks between institutions and researchers from Latin American countries is noteworthy. Joint cooperation between China and ASEAN countries prioritizes environmental cooperation.

The general purpose of this study is to identify opportunities for and to measure the existing collaboration on research and development between institutions from countries of Asia and Latin America within the FEALAC framework in the fields of biotechnology, nanotechnology, and their convergence. The purpose of this paper is to identify promising areas for international cooperation in the fields of nanotechnology and biotechnology, supported by corresponding proposals for governance cooperation frameworks.

In Section 2, the development of biotechnology and nanotechnology in the world and the FEALAC area is reviewed in countries such as the United States, Korea, Brazil, Japan and China. Section 3 is the review of a case study of heavy metal contamination that explains green technology as a factor of sustainable development and describes the scope and objectives of the current FEALAC's Network Convergence Bio-Nano Project coordinated by Colombia.[2] Section 4 develops a scientific and technological surveillance report identifying co-authorship in R&D (both articles and patents) among FEALAC countries in Asia and Latin America. The paper also evaluates both the R&D and innovation capabilities of those countries as well as the degree of international cooperation among countries from the two regions. Section 5 contains a study about the governance of international

[1] The Forum for East Asia-Latin America Cooperation (FEALAC) is an association of 36 countries from East Asia and Latin America that came together for the first time to form an official and regular dialogue channel between the two regions.

[2] For more information, see www.cbionano.org

cooperation in R&D that focuses on how effective international cooperation provides economies of scale and scope, especially when public budgets are tight. Nevertheless, currently there is limited conceptual and empirical research on the governance of international cooperation in STI, and a lack of indicators to inform policy (OECD, 2012). In Section 6, the conclusions and recommendations have regional and global contexts. Among the economic context of R&D cooperation, which may drive technological cooperation, it is worth examining the case of China-ASEAN countries. After improvement in bilateral political relations and the opening of the Chinese economy, for instance, the signing of the Framework Agreement on Comprehensive Economic Cooperation involving the ASEAN-China Free Trade Area (ACFTA) is an important milestone that has fostered closer trade and economic ties between the countries. Similarly, there are prospective benefits of a partnership between Latin America and China.

The research framework combines qualitative and quantitative aspects. The former consists of R&D cooperation case studies, and the latter uses scientific and technological queries of several databases. The research methodologies in the case studies include four dimensions to address themes conceived as global challenges: i) establishing regional and bilateral cooperation priorities of countries in both regions; ii) sharing knowledge and intellectual property management; iii) building capabilities for research and innovation; and iv) funding. The methodology for the investigation is based on case studies of cooperation modalities within each of the regions and among them, comparing international cooperation modalities in other regions of the world that are considered relevant to the FEALAC context.

2. BIOTECHNOLOGY AND NANOTECHNOLOGY IN THE WORLD AND THE FEALAC AREA

2.1. Bio and Nanotechnology in the Strategic Plan US NNI

In 2001, the federal government of the United States launched the National Nanotechnology Initiative (NNI) aimed at coordinating research activities, development, and cooperation in the areas of science, engineering, and technology (National Science and Technology Council Committee on Technology, 2014). The United States maintains its leadership in nanotechnology R&D through the NNI, which has led to major scientific breakthrough related to nanotechnology. Subsequently, there has been consolidation of strategic developments in technological applications and nanoproduct engineering. The NNI includes a robust infrastructure based on R&D centers, networks, and universities. The initiative makes nanotechnology a national level priority area, which has a strong social purpose and is focused on the training of future generations.

One of the most important features of the NNI is that it promotes the unification of the following converging areas: *nanotechnology*, *biotechnology*, *information science*, and *cognitive science* (Bainbridge & Roco, 2005). Instrumental capacity and phenomenological understanding of matter are providing access to scales where biotechnology and nanotechnology allow the control and manipulation of matter. The Obama Administration placed nanotechnology in a strategic sector with a high value of impact on the environment, health, and safety.

2.2. Biotech Crops in Asia and Latin America

Despite the current controversy involving biotech crops, Asia and Latin America have seen a significant increase in research and development in this field in recent years. More than twenty countries in Asia are involved in biotechnology, with China and Australia in the lead. In Latin America, Brazil, Argentina, Chile, Colombia, Costa Rica, Mexico, and Peru are incorporating these technologies for their commercial and environmental value. The third generation of biotech crops produces industrial products, which include biofuels as part of a strategy to reduce greenhouse gas emissions (Hautea & Cruz, 2007). Biotech crops make up more than 34% of the four crops of highest demand in the global market.

ASEAN identified nanotechnology as one of the strategic areas of cooperation between its member countries, with plant biotechnology as the basis for economic growth in the region (Hautea & Escaler, 2004). A recent bibliometric study shows that 7,907 papers related to plant biotechnology were published in the period between 2004 and 2013 (Payumo & Sutton, 2015). The study found the number of authors had an average growth of 200 authors per year in the observed period. The number of citations in the field was approximately 117,000 and the average number of citations per publication (CPP) was around 19.81. As the authors of the bibliometric study noted, this value is higher than the average CPP for all ASEAN publications (8.4). These results show the importance of the role biotechnology plays in the research and development programs and policies based on cooperation between Southeast Asian countries.

2.3. Nanotechnology in Korea

Korea has positioned itself as one of the world's leading countries in the area of nanotechnology. The Korea National Nanotechnology Initiative was launched in 2001 with a budget of USD 2 billion for its first decade. In Phase I of the initiative, covering the period between 2001 and 2005, Korea began to build R&D infrastructure for nanotechnology. Several R&D entities were created (e.g., the National NanoFab Center, Nanotechnology Information Support System, Application Nanoparticles Center, Nano Practical Convergence Center, and Nanoparticles TIC).

In 2005, the investment was 277.2 billion won with a growth rate of 3.8% in nano-related projects. There were more than 3,900 researchers, 214 companies, 38 departments, 1,421 papers, and 979 patents related to nanotechnology (Roco, 2005). Korea’s standing in nanotechnology jumped, ranking fifth in publications and fourth in patents worldwide. In 2007, Korean investment in nanotechnology reached 281 billion won. Other measures continued to rise: 274 companies, 56 departments, 2,236 papers and 1,769 patents. As a part of the initiative, the Nano Safety Management Master Plan was created in 2011. The plan sought to define methods and processes for the identification and management of safety risks associated with nanomaterials and nanotechnology products.

In Phase III (2011-2020), the National Nanotechnology Program shifted to market-oriented strategies that targeted sectors including information technology, nanobiotechnology, manufacturing, and energy/environment. Initiative Nano-Convergence 2020 is committed to investing around 500 million dollars over the next nine years.

2.4. Bio-Nanotechnology in Brazil

In Brazil, the following strategic areas have been selected for nanotechnology: energy, environment, defense, health, aerospace and agribusiness. A ministerial order of 2012 created the Inter-Ministries Nanotechnology Committee which included the Ministries of Science, Technology and Innovation, Environment, Health, Energy, Defense, Agriculture, Education, Industry, and Commerce. For the environment, research pursues new materials from biomass. In 2012, the government invested about US $ 44.5 million in nanotechnology.

The National Laboratories for Nanotechnology (SisNANO) Initiative is aimed at promoting cooperation between public and private partners to strengthen and optimize the research infrastructure and development in nanoscience and nanotechnology. About 16 institutes have been created that are currently dedicated to nanotechnology with at least 8 nanotechnology laboratories. More than 700 companies incorporating nanotechnology have been identified. In cooperation with national institutes and universities, 163 of these companies conducted R&D in nanotechnology (OECD/NNI, 2013).

In the Map Biotech Brazil 2011, biotechnology and biodiversity were recognized as vital to promote energy production, health promotion, and the supply of foodstuffs. These areas play an important role in the productive chain of the bio-economy.

Marine biotechnology has drawn many proposals for cooperation, particularly between research groups from different disciplines and professions. The existence of 402 research groups focused on marine biotechnology with researchers from 34 different areas was identified (Fausto & Mena-Chalco, 2015). Biotechnology is highly interdisciplinary and provides fertile ground for cooperation. In Brazil, research group leaders are fundamental for the consolidation and coordination of knowledge networks and cooperative activities.

2.5. Bio-Nanotechnology in Japan

Japan targets three subsectors for R&D in nanotechnology: green nanotechnology, nanobiotechnology and nanoelectronics. Its priority areas are energy, infrastructure and resources. Green nanotechnology is focused on power generation, transmission and storage that ensure environmental protection. Nanobiotechnology is oriented towards health and biological systems and applications in other fields. Nanoelectronics R&D is directed towards energy efficiency and ultra-fast computing.

The 2nd S&T Basic Plan of Japan introduced the regional Knowledge Clusters focused on R&D.

These were systems for technological innovation that were organized around universities, public research institutions and companies. The clusters were divided into life sciences, information technology, environment, and materials. During the 3rd S&T Basic Plan 2006-2010, the areas of greatest activity were the life sciences, information technology, environmental nanotechnology, materials, energy, manufacturing, and social infrastructure (OECD/NNI, 2013).

Investments during the 3rd S&T Basic Plan prioritized energy and life sciences, while the largest relative number of patents was in the area of nanotechnology and materials. For the 4th S&T Basic Plan 2011-2015, the environmental problem of carbon dioxide reduction was prioritized. The pillars of the Plan include security, recovery and reconstruction, green innovation and innovation for life, promotion of basic activities of R&D, and development of human capabilities.

2.6. Nanotechnology in China

China has reached a position of global leadership in nanotechnology. Today, it is a leader in production and application of carbon nanotubes, nanostructured coatings, nanomaterials used for optical applications, and nanoscale materials for use in the textile industry (Jarvis & Richmond, 2011). China's remarkable transition from scientific knowledge to the development of products derived from nanotechnology is reflected in its world-leading number of patents.

A study of the number of publications in nanotechnology, in the period between 1990 and 2006, identified the regions with higher activity resulting from international cooperation in Beijing, Shanghai, and Hong Kong (Tang & Shapira, 2011). The paper concludes that the rapid progress of nanotechnology in China is explained by the emergence of regional hubs of R&D with a high level of international cooperation. In China, there are over thirty institutions that conduct research on the toxicology and environmental impact of nanomaterials. They have increased the number of studies and progress in opportunities for re-use and recovery of nanomaterials from production processes.

3. CASE STUDY: HEAVY METAL CONTAMINATION

Heavy metal[3] contamination is one of the most important environmental problems worldwide. Either anthropogenic or natural, the pollution of heavy metals in water, air, and soil in undue concentrations causes a significant impact on the environment and welfare of living things. Heavy metals cannot be transformed into safe final products. Although many of them such as Mn, Cu, Fe, Zn, and Mb are necessary for the growth of living organisms and their processes, some others, such as Pb, Hg, Cd, Cr, and As (although As is technically a metalloid, it can be classified as a heavy metal), can be considered contaminants when present in soluble form and in undue concentrations.

[3] Heavy metals are regarded as a group of metals and metalloids with atomic density above 5 g/cm3 in this paper. Currently, there is no clear and standard definition of heavy metal. It is associated with metals and metalloids with potential toxicity to living organisms and the environment (Duffus, 2002).

The presence of heavy metals in water, specifically in water for human consumption, seriously compromises health and food safety. Concentrations higher than those recommended by the environmental and health authorities can cause severe intoxication and irreversible degenerative damage, muscular dystrophy, multiple sclerosis, melanomas, gangrene, hypertension, genetic disorders, chronic renal failure, skin lesions, and Alzheimer's disease. Some metals and prolonged exposure can produce carcinogenic effects. This makes it urgent to develop monitoring, detection, and measurement programs, as well as tools to improve understanding through modeling and simulation of the mechanisms and processes involving sources of contamination and the mobility of these contaminants through the environment. Furthermore, the development and implementation of sustainable remediation strategies capable of efficiently removing harmful metals present in the water, soil, and air is required.

As was mentioned, nanotechnology and biotechnology are emerging as strategic areas to deal with contamination. However, cooperation, socialization, and knowledge transfer are required to transform these emerging technologies into high-value solutions in responsibility and sustainability (Casals, González, & Puntes, 2012a).

3.1. Socialization, Cooperation, and the Problem of Heavy Metal Contamination

There have been several activities that focus on the socialization of heavy metal contamination. First, the International Society of Groundwater for Sustainable Development (ISGSD) plays an in important role in the socialization of heavy metal contamination. It has convened the International Congress on Arsenic in the Environment since 2006. This is one of the most important open forums to address the problem of arsenic contamination. The Congress has been held in Mexico (2006), Spain (2008), Taiwan (2010), Australia (2012), and Argentina (2014). These meetings provide a valuable exchange and transfer of knowledge leading to understanding the origin of arsenic contamination, its behavior in the environment, and its impact on human health and the management capabilities with associated risks. Additionally, it enables valuable interaction between academia, industry, research institutions and laboratories, and government agencies. In 2016, the 6th International Congress on Arsenic in the Environment on research and global sustainability will be held in Stockholm, Sweden.

Second, the Colombian Network for Nanoscience and Nanotechnology has conducted three national forums on mercury contamination, bringing together researchers, academics, students, businessmen and civil servants. At these meetings, experts gathered to contextualize the problem, to guide cooperation networks, to develop mechanisms to measure and monitor, to perform community service, and to perform environmental remediation of waters contaminated by mercury. From a state of the art review of the issue of mercury in Colombia, and as a result of the National Forums, it has become possible to draw a roadmap to work on local measurement and impact of mercury on health and food from the production and implementation of materials and clean processes (González, Marrugo, & Martínez, 2015).

The Single National Plan of Mercury implemented by the national government, which seeks to eliminate the use of mercury in mining and industrial sectors of Colombia gradually and definitively is also noteworthy. In order to minimize its impact on the environment and on human health, the plan establishes mechanisms to promote technology transfer, usage of clean technologies, and training and awareness on the use of mercury and products that contain it. The plan was agreed upon by eight ministries and two mining institutions (Ministerio de Ambiente y Desarrollo Sostenible. MINAMBIENTE, 2016).

3.2. Green Nanotechnology as a Factor of Sustainable Development

The modification of the physio-chemical properties of nanomaterials has high sensitivity to their surroundings. Once released into the environment, nanoparticles undergoes structural changes that make it difficult to predict its impacts. To assess the potential risks, the study of life cycle and environmental balance, both of the material after manufacture and of the process of synthesis are essential. In most cases, highly noxious chemical reagents are used in the production of nanomaterials with the byproduct of severe loss of sustainability and environmental protection (Jamier, Varón, González, & Puentes, 2012).

Green synthesis can lead to a healthier life cycle, based on more efficient and sustainable production of nanomaterials. In this approach, it seeks to eliminate the use of harmful substances in the manufacturing of nanomaterials through efficiency and waste management strategies. By improving management of waste and residue generated by the agricultural or food industries, resources can be captured for energy and nanomaterial use. Furthermore, the synthesis of nanoproducts from an alliance between bio and nanotechnology offers options for manufacturing with exceptional properties and use value.

3.3. The Need for Networking Based on Cooperation

The growing number of proposals reported in specialized magazines, as well as patenting activity in the areas of remediation and bioenergy, shows a critical mass of researchers of areas related to contamination by heavy metals and sustainable energy production. However, there is a lack of cooperation between disciplines, which is needed to resolve the research challenges. For example, in the use of materials and processes for remediation and energy production, the study and investigation of the behavior of the material and its use in the task of removal is also required. Furthermore, investigation of the life cycle of the materials used, their impact on health and the environment, energy consumption is crucial (Casals, González, & Puntes, 2012b). In its absence, the study of implementation of a material and process in the removal of the contaminant or in power generation may lead to positive results. However, if certain precursors or synthetic methods are neglected, results for its full-cycle production may actually produce an overall negative environmental impact.

For sustainable solutions to environmental pollution, it is necessary for different actors to address each facet of the potential solution within their area of expertise. In the case of environmental remediation, these are eco-toxicity, life cycle, mobility of the contaminant in the environment, and interactions with living beings. It is clear that addressing this problem from each area independently will not produce the desired results. It is essential to join efforts in a coordinated way, maintaining the focus on convergence towards a sustainable solution. It is a process based on cooperation, which is where bio and nanotechnology offer fertile ground for networking.

3.4. The Case of FEALAC's Network Convergence Bio-Nano

The Network Convergence Bio-Nano Initiative of the FEALAC Forum promotes an interdisciplinary and holistic approach to the problem of contamination and energy, which is in accordance with the opportunities offered by bio and nanotechnology. The initiative for cooperation between the countries of Asia and Latin America hosts two themes: environmental remediation (specifically of heavy metals in water for human consumption) and bioenergy.

Although the presence of heavy metals in water for human consumption is common in every country, especially in some countries belonging to FEALAC, the levels of contamination by heavy metals such as arsenic (considered a class-1 carcinogen) are above recommended levels. Over 100 million people are at risk of arsenic exposure through contaminated food and water in Asia and about 14 million in Latin America. In Mexico, Argentina, Chile, Brazil, El Salvador, Nicaragua, Peru, China, Taiwan, Thailand, Japan, Vietnam and Australia, arsenic concentration measurements are close to or above the maximum recommended by the World Health Organization. In other countries, the levels of contamination and population exposed to arsenic are still unknown. In a considerable number of countries, arsenic, mercury, lead, and cadmium are present in water in concentrations with high risks for health and the environment. Heavy metal contamination is one of the most sensitive and urgent environmental issues.

4. BIOTECHNOLOGY AND NANOTECHNOLOGY R&D RELATIONSHIPS BETWEEN FEALAC COUNTRIES

In order to find the relationship between FEALAC countries, we queried the Scopus[4] and Thomson Innovation[5] databases for articles and patents in biotechnology and nanotechnology, respectively. Data analysis and data mining were done using Vantage Point[6] software.

[4] "Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings. Delivering a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities, Scopus features smart tools to track, analyze and visualize research (RELX Group, 2016)."

[5] "Thomson Innovation brings together the world's most comprehensive international patent coverage and the industry's powerful intellectual property (IP) analysis tools (Thomson Reuters, 2016)."

4.1. Search and Data Analysis of Scientific Articles

The keywords selected to search for articles and patents in the Scopus database were based on information and related themes gathered from expert Edgar Gonzalez; then, search algorithms were executed using the keywords.

TABLE 1 shows that the number of articles published in both Nanotechnology and Biotechnology are large. Countries within FEALAC Asia (Japan, China, South Korea and Singapore) have more publications in nanotechnology than FEALAC countries in Latin America (Mexico, Brazil, Chile and Colombia). A similar pattern is seen in biotechnology. The articles that were published on both areas in FEALAC countries, the numbers and margins are similar.

TABLE 1. Articles: Boolean Queries

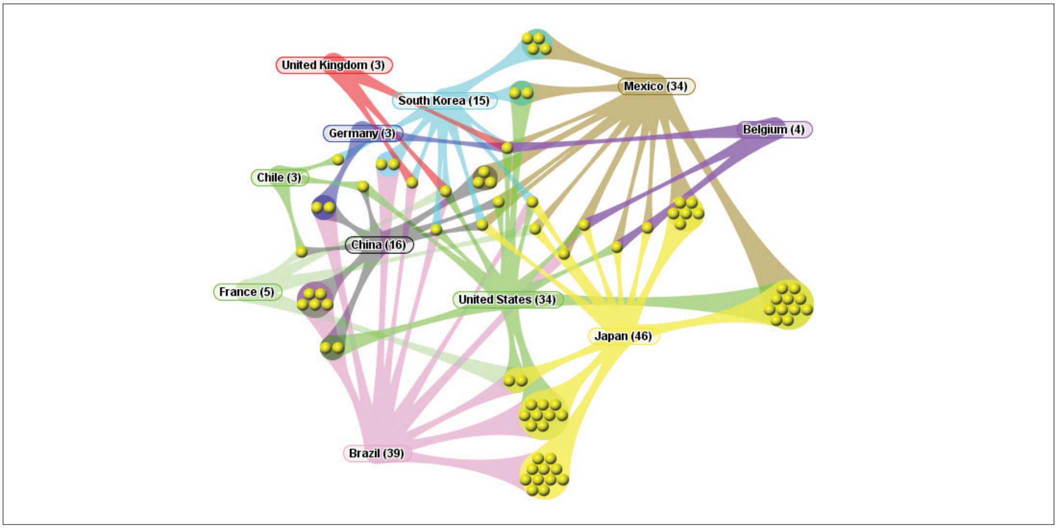
ID	QUERY	ARTICLES	DESCRIPTION
1	TITLE-ABS-KEY (nanotechnology)	114,267	Nanotechnology
2	TITLE-ABS-KEY (nanotechnology) AND AFFILCOUNTRY (Japan OR China OR Korea OR Singapore)	27,827	FEALAC Asia
3	TITLE-ABS-KEY (nanotechnology) AND AFFILCOUNTRY (Mexico OR Brazil OR Chile OR Colombia)	824	FEALAC Latin America
4	TITLE-ABS-KEY (nanotechnology) AND AFFILCOUNTRY (Japan OR China OR Korea OR Singapore) AND AFFILCOUNTRY (Mexico OR Brazil OR Chile OR Colombia)	74	FEALAC Countries
5	TITLE-ABS-KEY (nanotechnology) AND AFFILCOUNTRY (China) AND AFFILCOUNTRY (Brunei Darussalam OR Cambodia OR Indonesia OR Laos OR Malaysia OR Myanmar OR Singapore OR Thailand OR Philippines OR Vietnam)	321	ASEAN Countries
6	TITLE-ABS-KEY (biotechnology)	119,369	Biotechnology
7	TITLE-ABS-KEY (biotechnology) AND AFFILCOUNTRY (Japan OR China OR Korea OR Singapore)	22,550	FEALAC Asia
8	TITLE-ABS-KEY (biotechnology) AND AFFILCOUNTRY (Mexico OR Brazil OR Chile OR Colombia)	3,560	FEALAC Latin America
9	TITLE-ABS-KEY (biotechnology) AND AFFILCOUNTRY (Japan OR China OR Korea OR Singapore) AND AFFILCOUNTRY (Mexico OR Brazil OR Chile OR Colombia)	65	FEALAC Countries
10	TITLE-ABS-KEY (biotechnology AND crop) AND AFFILCOUNTRY (Japan OR China OR Korea OR Singapore) AND AFFILCOUNTRY (Mexico OR Brazil OR Chile OR Colombia)	12	FEALAC Countries + Crops
11	TITLE-ABS-KEY (biotechnology) AND AFFILCOUNTRY (China) AND AFFILCOUNTRY (Brunei Darussalam OR Cambodia OR Indonesia OR Laos OR Malaysia OR Myanmar OR Singapore OR Thailand OR Philippines OR Vietnam)	75	ASEAN Countries

Source: Scopus 2016
Note: TITTLE-ABS-KEY: Tittle, abstract and keyword; AFFILCOUNTRY: Affiliation country.

[6] "Vantage Point is a powerful text-mining tool for discovering knowledge in search results from patent and literature databases. The perspective provided by VantagePoint enables you to quickly find WHO, WHAT, WHEN and WHERE, helping you clarify relationships and find critical patterns (Search Technology Inc., 2016)."

After reviewing the results from each of the above algorithms (TABLE 1), it was decided to focus on those showing the interaction between FEALAC countries in nanotechnology and biotechnology (algorithms 4 and 9, respectively). The results are graphed to show the relationships between countries (in different colors) and to the coauthors of scientific articles (FIGURES 1 & 2). Next to the name of each country there is a number corresponding to the number of articles published by that country (e.g., Japan has 46 items). The branches connecting the countries show the relationships of coauthored publications (e.g., Japan is related to Mexico, Belgium, United Sates, China, South Korea, France and Brazil). Finally, yellow dots at the intersections between countries show the number of items in which they have worked together (e.g., Brazil and Japan have published 11 coauthored items).

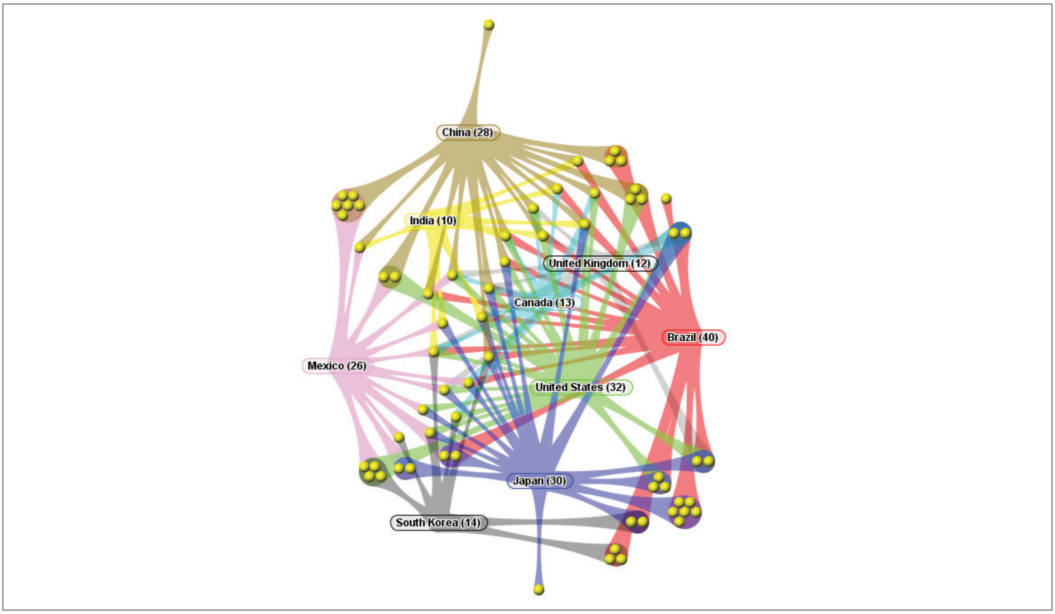
FIGURE 1. Nanotechnology Articles by FEALAC Countries (74)



Source: Vantage Point 2016

FIGURE 1 shows that countries such as Japan, Brazil, Mexico and United States possess the higher numbers of co-authorship in nanotechnology. As for FEALAC countries, countries such as Japan, Brazil and Mexico combined have the greatest number of publications. In addition, Japan works with almost all FEALAC countries (Brazil, China, South Korea and Mexico), which shows that nanotechnology research can be a driver for collaborative initiatives in scientific publications within FEALAC.

FIGURE 2. Biotechnology Articles by FEALAC Countries (65)



Source: Vantage Point 2016

FIGURE 2 shows that countries such as Japan, Brazil, China, Mexico and United States possess the highest numbers of co-authorship in biotechnology. For FEALAC countries, Japan, Brazil and Mexico and China have the greatest number of collaborative projects. In addition, Japan works with almost all FEALAC countries (Brazil, China, South Korea and Mexico), which shows biotechnology can be a driver for collaboration initiatives in scientific publications within FEALAC.

In FIGURE 1 and FIGURE 2, South Korea is close to the leaders mentioned above and will quite possibly become a leader in a few years.

4.2. Search and Data Analysis of Patents

The keywords selected to search for articles and patents within the Thomson Innovation database were obtained based on information and related themes gathered by expert Edgar Gonzalez; then, search algorithms were executed using the keywords.

TABLE 2 shows that the number of patents in nanotechnology is not as high as in biotechnology which was not originally expected. For FEALAC countries in Asia (Japan, China, South Korea and Singapore), the number of patents in nanotechnology is greater than it is for FEALAC countries in Latin America (Mexico, Brazil, Chile and Colombia), but the difference is smaller than it is for articles (algorithms 2 and 3, TABLE 1). Despite producing articles in both fields, articles—even when coauthored by researchers in both regions—do not lead to patents held in FEALAC countries in Asia and Latin America (algorithms 15 and 20, TABLE 2).

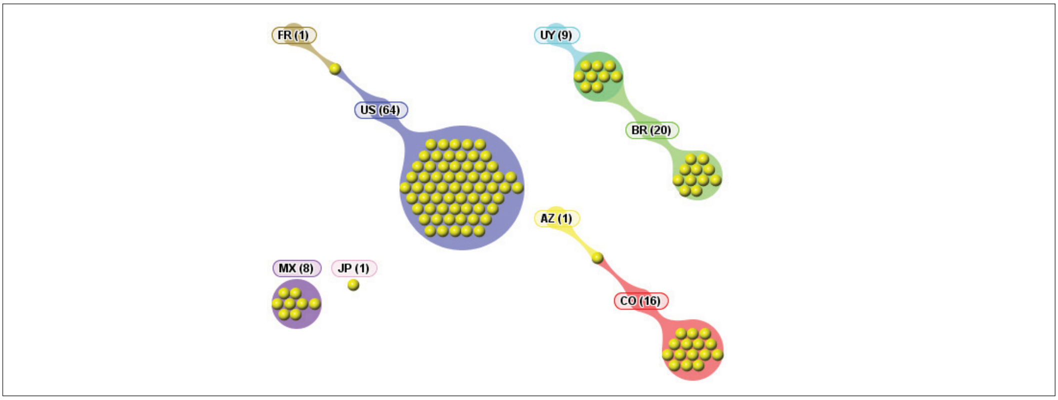
TABLE 2. Patents: Boolean Queries

ID	QUERY	PATENTS	DESCRIPTION
12	CTB=(nanotechnology)	2,364	Nanotechnology
13	CTB=(nanotechnology) AND INAD=(Japan OR China OR Korea OR Singapore)	463	FEALAC Asia
14	CTB=(nanotechnology) AND INAD=(Mexico OR Brazil OR Chile OR Colombia)	109	FEALAC Latin America
15	CTB=(nanotechnology) AND INAD=(Japan OR China OR Korea OR Singapore) AND INAD=(Mexico OR Brazil OR Chile OR Colombia)	0	FEALAC Countries
16	CTB=(nanotechnology) AND INAD=(China) AND INAD=(Brunei OR Cambodia OR Indonesia OR Laos OR Malaysia OR Myanmar OR Singapore OR Thailand OR Philippines OR Vietnam)	0	ASEAN Countries
17	CTB=(biotechnology)	14,761	Biotechnology
18	CTB=(biotechnology) AND INAD=(Japan OR China OR Korea OR Singapore)	326	FEALAC Asia
19	CTB=(biotechnology) AND INAD=(Mexico OR Brazil OR Chile OR Colombia)	12	FEALAC Latin America
20	CTB=(biotechnology) AND INAD=(Japan OR China OR Korea OR Singapore) AND INAD=(Mexico OR Brazil OR Chile OR Colombia)	0	FEALAC Countries
21	CTB=(biotechnology AND crop) AND INAD=(Japan OR China OR Korea OR Singapore) AND INAD=(Mexico OR Brazil OR Chile OR Colombia)	0	FEALAC Countries + Crops
22	CTB=(biotechnology) AND INAD=(China) AND INAD=(Brunei OR Cambodia OR Indonesia OR Laos OR Malaysia OR Myanmar OR Singapore OR Thailand OR Philippines OR Vietnam)	0	ASEAN Countries

Source: Thomson Innovation 2016
Note: CTB: Tittle, abstract and keywords, INAD: Inventor Address.

Given the lack of patenting across the FEALAC regions, we decided to work on those showing interaction between FEALAC Latin American countries (algorithms 14 and 19, TABLE 2) to review the dynamics leading to such a small number of publications. The results are graphed to show the relationships between countries (in different colors) and to the patenting relationships (FIGURES 3 & 4).

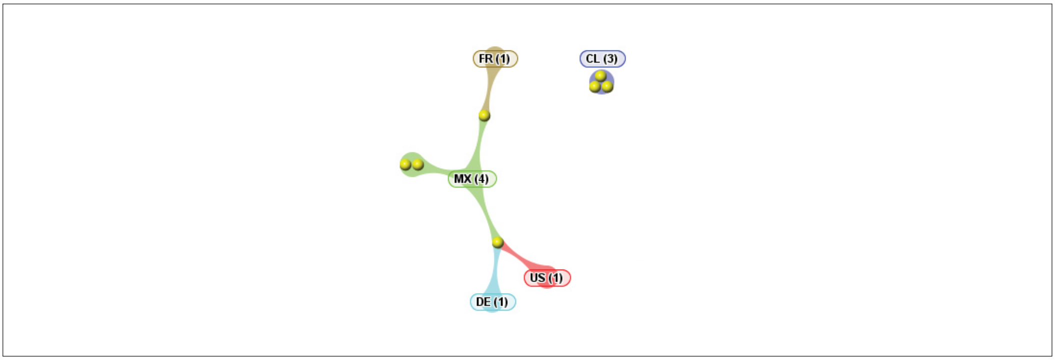
FIGURE 3. Nanotechnology Patents FEALAC Latin America (109)



Source: Vantage Point 2016

FIGURE 3 shows that, of the FEALAC countries in Latin America, Brazil (BR) and Colombia (CO) have the most patents in nanotechnology. In this case Brazil stands out for its number of co-inventions with Uruguay (UY), with 9 patents in nanotechnology.

FIGURE 4. Biotechnology Patents FEALAC Latin America (12)



Source: Vantage Point 2016

FIGURE 4 shows that, of the FEALAC countries in Latin America, Chile (CL) and Mexico (MX) have the most patents. However, despite collaborating with other countries (Germany (DE), United States (US), France (FR)), and Mexico shares none of its patents with FEALAC countries. This shows that relationships between FEALAC countries are not yielding the intended or potential results in co-inventions and subsequent patents. Additionally, when comparing the graphs of patents and articles in both fields, it is observed that dynamics involving patents are very weak in FEALAC countries.

5. GOVERNANCE OF INTERNATIONAL COOPERATION IN R&D

The environment and energy are global challenges that are intertwined, especially as the impacts from them spread in size and geographic location. The technological response expands, in tandem, across more sophisticated and complex sources of knowledge including biotechnology and nanotechnology. As a result, governance, which includes state and non-state actors, needs greater cooperation, coordination, and policy making to address the challenges. These actors engage in governance as the process of defining principles, rules, regulations and decision-making procedures (OECD, 2012).

Four dimensions of governance of STI international cooperation are used in this analysis (OECD, 2012): 1) the establishment of cooperation priorities in the countries within both regions and between them; 2) the sharing of knowledge and intellectual property management; 3) the funding of STI activities; and 4) the building of research and innovation capacity.

Those dimensions are used as criteria to review specialized literature and case studies included in the OECD Report. The following cases were first reviewed for their emphasis on those dimensions: the Group on Earth Observations (GEO) and the Inter-American Institute for Global Change Research (IAI) for their notions on capacity building, the Bill and Melinda Gates Foundation for innovative funding mechanisms and intellectual property management, and the Consultative Group on International Agricultural Research (CGIAR) for its knowledge policies. This first group of cases is completed by the International Atomic Energy Agency, the International Energy Agency and the Global Carbon Capture and Storage Institute. Two cases were also reviewed: China and Southeast Asian countries, and a prospective partnership between Latin America and China.

A recent approach regarding the relationship between science and policy in an environmental context, i.e., epistemic and legal institutions, has been adopted that considers that the degree and kinds of independence between them depends on a set of factors. In contrast with academia in international law, which suggests that expert bodies that give policy-relevant scientific advice, "epistemic institutions," should be autonomous from the institutions that use such advice as input to make international legal rules, "legal institutions (Meyer, 2013)."

The epistemic institutions' missions involve functions such as research and development, technology transfer, compilation, and dissemination of research about technological solutions to environmental problems. Examples of these are the Intergovernmental Panel on Climate Change, the World Health Organization (WHO), the International Renewable Energy Agency, the International Atomic Energy Agency, and the Inter American Institute for Global Change Research. Legal institutions are the ones empowered to make legal rules and adopt cooperative policies. Examples of these include organizations that are embedded in larger regimes such as the Conferences of the Parties, linked to any number of international environmental agreements or the WHO Dispute Settlement Body.

The core statement of this conceptual approach involves two scenarios. Wherever collective action is necessary to address a global environmental problem, hierarchy is the optimal relationship between legal and epistemic institutions, as hierarchy is the best means of ensuring the availability of a scientific record that is credible to the states bargaining in the international legal institution. While fragmentation is probably the optimal mode of organization, in cases of policy coordination it can take place without collective decision-making in international institutions (Meyer, 2013).

Epistemic institutions should be independent from legal institutions when there are a wide range of actors that perceive a real benefit in each country. Such independence allows them to act on the basis of scientific or technical information produced by an epistemic institution in a way that will result in coordination without the need for legal constraints. In contrast, the integration of epistemic institutions into legal institutions is justified in situations in which the provision of scientific information does not change the state's incentives to regulate unilaterally, and thus enables collective action to coordinate environmental policies across countries.

5.1. Establishment of Priorities for R&D Cooperation

According to the OECD report, priority setting is a negotiation process that results in common goals, objectives and actions. The identification of global challenges and their presence in the agenda is a precondition for priority setting. Some sources of tension can appear during priority-setting processes between stakeholders and actors: specialization vs. diversification, supply vs. demand-led orientation, diverse time horizons and uncertainty about resources. There are two different approaches for setting priorities on science, technology, and innovation: a technology-oriented approach based on the identification of key technologies for civilian purposes and a mission-led approach defined by new societal challenges. The cases reviewed show different levels of involvement and control in the priority-setting processes. A "variable geometry approach" means that not all stakeholders need to be involved in specific topics and activities, but this approach is prone to capture by the interests of more influential and well-endowed actors. Another approach balances between a top-down and a bottom-up approach based on the scientists' influence by steering priorities away from the sometimes biased and subjective interests of some actors and stakeholders.

Governance frameworks should be designed to contribute to the balance between competing interests and, at the same time, to achieve efficiency goals. Hence, a mix of bottom-up and top-down approaches counteracts the risk of possible biases in priority-setting because more actors and interests are involved. Inclusive supply-led and demand-driven approaches are needed in which the participation of scientific communities, policy makers, and society is guaranteed. Finally, an effective priority-setting process should consider budgetary and implementation issues from the start.

5.2. Sharing Knowledge and Intellectual Property Management

It should be noted from the outset that the role of patents and their monopolistic effects differ depending on the industrial sector, technology, and product. On the other hand, the important trends in innovation processes could have an influence in intellectual property (IP) management as "open innovation (Chesbrough, 2003)" becomes more pervasive; this shift toward openness requires different intellectual property management guidelines, as licensing processes begin to be used as more than just a defense of intellectual property rights (IPR) against competition.

Research suggests the relative importance of technology transfer compared to foreign direct investment and external trade openness. First, technology transfer can play an important role in enhancing the absorptive capacities of developing countries to contribute to their technological catch-up (World Intellectual Property Organization. WIPO, 2016). Second, trade openness seems to contribute the most among the three channels, followed by technology transfer (Sawada, Matsuda, & Kimura, 2012).

Sharing knowledge implies the use of multilateral collaborative mechanisms such as patent pools, clearing houses, consortiums, and joint ventures. Consortiums and joint ventures have the advantage of shared goals and strategies among the partners. Also, they take a relatively shorter period from the planning and launching of the project to the production of results.

The Golden Rice patent pool example clearly shows that IPR is not an impediment for the use and dissemination of a technology among poor people. Apart from being national in scope and limited in time, patent owners can decide to whom they license and under what terms (Golden Rice Humanitarian Board, 2016). As an example, CGIAR uses patent pools collaboratively to produce public goods at the regional or global levels.

Nonetheless, there are some limitations of the IPR system. It does not generate enough incentives for innovation because it can create "patent thickets," blocking patents, and "patent trolls (Stiglitz & Greenwald, 2014)." In the field of nanotechnology, a patent thicket has emerged as an ''intellectual property tragedy'' limiting the sharing and the use of critical knowledge, hindering downstream innovation, and preventing the development of more complex technologies due to exorbitant transaction costs. Hence, patenting nanotechnologies actually reduces commercial competition by making the use of some nanotechnologies highly expensive. Moreover, a number of nanotechnology patents cover basic science, which raises serious questions about the ownership of science (Pearce, 2013).

Furthermore, in some cases, as in the health sector, the patent system generates monopolistic power, which restricts production and reduces incentives for innovation (Stiglitz & Greenwald, 2014). Patent holders in the health sector often extend the life of patents by methods like devoting research to "me-too" drugs rather than the development of an effective medicine, or by delaying the use of scientific data by generic producers (Stiglitz & Greenwald, 2014).

The results justify finding and proposing alternatives for generating incentives for innovation based in previous measures, such as the Prize Fund for HIV/AIDS Act, a congressional bill introduced in the United States, and the "Research and Development to Meet Health Needs in Developing Countries" report, released by the WHO in 2012 (Stiglitz, 2012).

Regarding open data initiatives, the Group on Earth Observations, as an international partnership, practices the principle of "full and open exchange of data." The IAI intends to implement full and open exchange of scientific information and ensures free access to data generated by IAI-funded projects.

Putting effective management strategies into practice for IP for research and innovation collaborations depends on learning how to respond to different combinations of factors including i) types of IPR, ii) size and missions of private companies involved, iii) size of industrial sectors, and iv) public research organizations.

5.3. Funding and Spending Arrangements

This section is analyzed based on the OECD Report, the Meeting Challenges through Better Governance (OECD, 2012). It is crucial to strike the right balance between core and project funding. Voluntary and in-kind contributions may be useful for securing funds easily and quite quickly, but they may hamper the sound design of solid medium and long-term strategies. Criteria of fair returns are common in intergovernmental activities, but altruism may be needed in some fields such as global health. Therefore, an altruistic approach should be coupled with more conventional foreign aid for STI tasks related to addressing global challenges. On the other hand, strengthening local capacity and absorptive capacity building is needed to tackle global challenges, which requires sound allocation of resources in developing countries and the establishment of close links between STI and productive development policies.

The private sector expects reasonable returns on its investments, which involve issues of demand, access to markets, legal framework, and IPR. Therefore opportunities for the private sector might involve co-funding schemes. The Gates Foundation, which allows certain flexibility regarding IPR and research contracts, has been able to make collaborative research initiatives attractive to the private sector. The Gates Foundation provides an interesting case: the International Finance Facility for Immunization (IFFIm), which uses long-term pledges from donor governments to sell "vaccine bonds" in capital markets, makes high levels of funds immediately available for GAVI programs.[7] Bonds are issued on global capital markets against the security of government guarantees to maintain future aid flows, which can be used to buy back the bonds over a longer period. This allows a large amount of aid to flow immediately, at the expense of less aid in the future[8].

There is no single best funding and spending model for governance. Among the various alternatives, the balance between core and project funding stands out. This requires the balance between inclusiveness and efficiency in the priority-setting process or between broad accountability and efficient decision making, and a reduction in endowment asymmetries (OECD, 2012).

5.4. Capacity Building for Research and Innovation

It is useful to distinguish between a "narrow" and a "broad" STI cooperation paradigms (OECD, 2012). The former aims to achieve research excellence focusing on building scientific and technology capacity. The latter has scientific and non-scientific objectives that include societal challenges and incorporate the urgency and the extent of the global challenges. Broad cooperation suggests not only combining scientific and traditional or common sources of knowledge, but a more active role from partners in developing countries. Meeting global challenges needs scientific progress, tech-

---

[7] The GAVI Alliance is a global health initiative set up to enable better access to new and underused vaccines in developing countries.

[8] www.iffim.org/

nological innovation, and the successful application of existing and new technologies. An active role of the state is required for the promotion of productive development due to existing market and system failures.

Strengthening innovative capacity requires special partnerships between multiple actors aiming to i) accumulate scientific knowledge, ii) to absorb existing technologies, and iii) to generate solutions based on new combinations of knowledge.

Capacity building is a main activity for GEO, CGIAR and IAI. GEO "intends to build the capacity of individuals, institutions, and infrastructures to benefit from and contribute to the Global Earth Observation System of Systems (GEOSS), particularly in developing countries (GEO, 2009 as cited in OECD, 2012, p. 193)." CGIAR allocates about 20% of its budget to fund capacity building and technology transfer. The IAI supports interdisciplinary and collaborative research aiming to build scientific capacity throughout the Americas. For this goal, the IAI has put new mechanisms in practice to integrate different institutional, programmatic, financial, educational, and scientific objectives.

According to the OECD (2012), the governance options for capacity building need effectiveness that can be achieved by i) participatory learning and capacity building; ii) the inclusion of the establishment of mechanisms for STI initiatives in the current "state of the art" approach, for them to be more closely linked to local needs and stakeholders demands; and iii) the active engagement of recipients in the capacity building process: design, implementation and evaluation of issues that concern them.

5.5. Case Studies

We will develop the following two case studies: China and Southeast Asian countries and a prospective partnership between Latin America and China. The first case was chosen for two reasons: One is that environmental cooperation is prioritized, and the second reason is that there is much room for strengthening R&D cooperation between these countries. The prospective case is chosen for the fact that China's economic rebalancing poses challenges for Latin American countries. It also introduces key opportunities which will need to be addressed in the future development strategies of both regions, including those of international R&D cooperation.

5.5.1. China and Southeast Asian Countries

This section is analyzed by authors based on the OECD reviews of innovation policy of Southeast Asia (OECD, 2013). China and Southeast Asian countries have held "10+1" summits since 1997. During the 12th China-ASEAN Leaders Summit held in Thailand in 2009, the China-ASEAN cooperation strategy on environmental protection was passed to enhance cooperation in the fields of biodiversity conservation, ecological protection, cleaner production, environmental protection industry, new energy, and renewable energy.

Areas for cooperation have been prioritized at these summits; for example, the foundation of the China-ASEAN Cooperation Centre on Environmental Protection in 2010. Also the Fifth China-ASEAN Leaders Summit held in 2001 identified five priority areas for cooperation in the 21st century: ICT, environment, agriculture, human resource development, and education.

Environmental cooperation is another priority area with mechanisms such as the China-ASEAN Environment Ministers Meeting, the Environmental Ministerial Meeting on the GMS (Greater Mekong Sub-region), and the China-ASEAN Centre for Environmental Protection. The priority areas for cooperation include the implementation of the Plan for the GMS Biodiversity Conservation Corridors Initiative.

In regards to sharing knowledge and intellectual property issues, there exists very little cooperation shown by the fact that in 2008 only 76 of 412,000 domestic patents were granted by China to Southeast Asian (SEA) countries. In contrast, 81 of 10,176 patents to foreign countries were granted by SEA countries to China. China has a limited number of collaborative projects with SEA countries, with the exception of Singapore. This is reflected in the joint publication of scientific papers in the period from 1999 to 2010. Although co-authored publications rose steadily, they account for an insignificant share of the 472,000 Chinese scientific papers published internationally.

Regarding *capacity building*, first it must be underlined that, in STI cooperation between China and SEA countries, support is only indirect and generic, such as academic exchanges and activities. By 2009, 229,000 of Chinese students were studying abroad, of which 68,510 were studying in SEA countries. In 2009, there were around 230,000 foreign students studying in China, of which 34,735 were from ASEAN countries. Cooperation on education between China and SEA countries is expected to increase in the future. The main conclusions and projections of China-SEA country cooperation on STI are the following:

- Although progress has been quickly made in the field of bilateral economic cooperation, the progress in bilateral technological relationships is relatively weak.
- There is much room for improving knowledge sharing and cooperation in intellectual property.
- Among the factors favorable to S&T cooperation in the region, its economic context shows that countries are presently making an effort to restructure their industrial base from labor-intensive to technology-intensive industries and paying attention to green technology and the introduction of clean technology.

Concerning some future trends of S&T cooperation it would be worth mentioning:

- The great potential for China-ASEAN S&T cooperation based on their complementarities.
- The scale and quality of bilateral S&T cooperation is likely to improve, given the increase in the funds provided by China and the maturity of the cooperation mechanisms.
- S&T is an effective means of helping China and developing SEA countries respond to envi-

ronmental challenges and those related to energy and renewable industries, to promote sustainable economic development and common prosperity, and to ensure security.

5.5.2. The Prospect of a Partnership between Latin America and China

This is a “special” case and it is necessary on several levels. It is only a “real” case because it is currently under construction though their commercial and financial links have dynamically grown during the last two decades. Its study is necessary as a comprehensive and overall context for science and technology international cooperation, aiming to promote research and development in important fields such as nanotechnology and biotechnology applied to overcoming environmental challenges in FEALAC countries. This case study is analyzed based on the OECD work (OECD/ECLAC/CAF, 2015) for the cooperation outlook between Latin America and China.

First of all, China’s so called new normal development model responds to the need for a more sustainable growth path to overcome the perils of falling in the middle-income trap, shifting to higher consumption, diversification and sophistication, and strengthening the population's skills.

Regarding *priority settings*, some facts influence and are related to productive specialization patterns. The trade links between Latin America and China will continue to be a key feature in the medium and in the long term, but traditional commodity exports will significantly reduce due to China’s shift from investment and exports towards consumption. Several medium and long term scenarios show that Latin American exports to China will experience a significant slowdown of different intensities according to the exports baskets and their exposure to the country. Fossil fuel, mining, and ore exporters will experience decelerations. Nonetheless, China’s rebalancing involving the re-composition of consumption introduces opportunities for Latin American exports in certain agro-food sectors, services, and manufacturing.

By 2040, certain trends will impact the food market in China. East Asia will become a world leader in bioscience by responding to the need to improve agricultural incomes. East Asia offers major opportunities for food products with special properties, as the region has a long standing tradition of using diet to achieve health objectives.

Addressing these challenges implies public-private agreements on active productive development policies (PDP) in Latin American countries at both national and regional levels. Regional and world experiences in productive development policies as responses to modest economic growth imply covering both a dimension (i.e., horizontal or vertical) and a type of intervention (i.e., public goods or market interventions). This PDP approach responds to the need to counteract market and state failures (Inter-American Development Bank, 2015). Its contents include cluster-based mechanisms, fostering innovation, upgrading skills and mobilizing financial resources, upgrading governance, and strengthening regulatory frameworks.

With vast natural and water resources, Latin America has comparative advantages to become one of China’s suppliers of nutritious, safe, and high-quality food products. Environmental degradation, however, is an overarching threat stemming from the traditional exports to China based on mineral extractions and agricultural products, which are environmentally damaging sectors.

In 2014, China and the Community of Latin American and Caribbean States, CELAC, announced the establishment of the China-Latin America comprehensive cooperative partnership and the formal establishment of China-CELAC. This relationship highlights certain areas for collaboration in STI:

- Infrastructure: agriculture, energy, and power
- Education and human resources training: promotion of exchanges, research mobility programs, and cooperation between education departments and institutions

There are several examples of collaboration that have already started including the Brazil-China Ten Year Cooperation Plan (2012-21), Chile's energy diversification targeting an ambitious solar energy plan, and the Argentinean-Chinese Centre of Science and Food Technology in the areas of agri-food, biotechnology, nanotechnology, energy, sustainable food processing, preservation, packaging, and transport research.

Actually, *capacity building* has fewer options for collaboration. Given that the quality of education in Latin America is still low relative to the challenges posed, the outputs of each partner would lead to competition. The high-graduation rates in China would aggravate the gap, as China captures high value-added segments of global value chains, producing more sophisticated goods and developing its services sector. In sharp contrast to China, the composition of skills in Latin America is focused in fields less connected to the productive economic sector and there exists under-investment in science and technology.

Furthermore, beyond the increase in the quantity of skills, the challenges for both Latin America and China remain in the labor sector like quality, pertinence, and matching the available skills with the economy. In order for Latin America to compete and tap into emerging opportunities, skills need to be upgraded and the quality of the education and training systems needs to be improved, not only in the more traditional education paths, training throughout the work-life cycle, and mechanisms to provide workplace training to update and renew workers' skills are required. The main conclusions from this case study are the following:

- It would be better in the STI priority-setting process to consider the outcomes of active productive development policies derived from the opportunities in the projected links with China.
- Latin America's pool of skills needs to be improved with the aim of supporting productivity gains and more value-added goods, strengthening firms along the global value chains.

6. CONCLUSIONS AND RECOMMENDATIONS

To summarize, nanotechnology, biotechnology, and their convergence contribute to solving the environmental problems of contamination by heavy metals and of those arising from accelerated rate of energy consumption. These scientific developments in bio refinery technologies provide new business opportunities.

Insofar as FEALAC's Network Convergence Bio-Nano initiative currently works on the formulation of four international cooperation projects, three of them involve nanotechnology and biotechnology for remediation, and one regarding bio-refinery[9] the goals and impacts are clearly perceived by every country. Therefore ongoing projects in their execution stage or new similar ones should be better linked to independent epistemic institutions such as universities, and public or private research centers, while maintaining a joint network scheme.

An important aspect, in which FEALAC's Network Convergence Bio-Nano plays an important role, is the possibility of establishing consensus on regulations and standardization for risk assessment of contamination by heavy metals and measurement protocols. This would enable the development of pollution maps for diagnosis, in order to identify and draw up the mitigation and remediation strategies formulated with bio and nanotechnology.

The study provides implications concerning the key components of a dynamic and evolutionary STI public policy in the context of FEALAC. Regarding intellectual property management, it should be noted that "patent thickets" have emerged in the field of nanotechnology, so it would be justified to experiment with a prize system, e.g., a FEALAC governments-supported prize fund, in which innovators are rewarded in return for new knowledge, but without retaining a monopoly on its use as a key element for supporting FEALAC collaborative projects in nanotechnology and biotechnology for remediation with expected or non-private returns. With a system like this, once a technology is developed, it is made available in the FEALAC Network developing countries at a fair price, or a free and open-source (FOSS) paradigm from software development can be applied. Open-source methodologies will both accelerate nanotechnology innovation and improve the social returns from public investment in nanotechnology research.

In contrast, research about specific, non-profitable nanotechnologies should be undertaken for environmental and social benefits conceived as a public good provided by the state, aiming to address a market failure that hampers the resolution of global challenges such as contamination by heavy metals or climate change caused by greenhouse gas emissions. In this scenario, the next execution stage of FEALAC Network projects will be supported by collaborative open calls for proposals funded by governments of countries in the FEALAC Network.

---

[9] The results of the first international Workshop on March 2016 are available in http://cbionano.org/?page_id=1069

By sharing knowledge and technology, developing countries will improve capacity building in R&D. At the current stage of the Bio Nano FEALAC Network, a participatory methodology has been adopted, which includes international workshops and dissemination mechanisms. These mechanisms are designed to strengthen the capabilities and skills of people in developing FEALAC countries and to improve high-end R&D and innovation quality.

As the global challenges increase, greater interdisciplinary participation and broader stakeholder participation are required. The scientific and technological gap in developing FEALAC countries requires a partnership composed of a wide range of actors, which calls for greater capacity to meet the required standards.

In order to develop new solutions or innovate from the mix of different types of knowledge, capacity building should involve not only investments in scientific capacity, but strengthening numerous skills and activities, such as the ability to use and manage existing scientific and technological knowledge, products and skills. This suggests the need for partners from developing FEALAC countries to play a more active role. The next stage of the FEALAC Network will set up specific multi-agent structures (e.g., networks, clusters, sectors, markets, industries, and product classes, which will ensure effectiveness in project execution).

Since it provides opportunities of accessing knowledge, a free, open-source technology capacity building development approach would lead to strengthening scientific and high-end technology skills, creating a virtuous cycle.

Additional innovative mechanisms should be developed for funding and spending issues. In convergence with the proposal for alternative methods of intellectual property protection should first be developed for the national context, and then in the medium and long term in a regional context. We suggest an experimental mechanism similar to the funding facility IFFIm and/or a government-supported prize fund with the purpose of allowing larger support to flow for R&D in the nanotechnology and biotechnology fields for environmental and social benefits. In the future, the IFFIm for nanotechnology and biotechnology remediation could be implemented in each of the FEALAC regions: Latin America and ASEAN countries and later expanding to involve countries in both regions.

REFERENCES

Bainbridge, W., & Roco, M. (2005). *Managing nano-bio-info cogno innovations: Converging technologies in society*. Dordrecht: Springer.

Casals, E., González, E., & Puntes, V. (2012a). Inorganic nanoparticles and the environment: Balancing benefits and risks. In D. Barcelo & M. Farre (Eds.), *Comprehensive analytical chemistry vol. 59: Analysis and risk of nanomaterials in environmental and food samples* (pp. 265-290). Amsterdam: Elsevier.

Casals, E., González, E., & Puntes, V. (2012b). Reactivity of inorganic nanoparticles in biological environments: Insights into nanotoxicity mechanisms. *Journal Of Physics D: Applied Physics, 45*(44), 1-45.

Chesbrough, H. (2006). *Open innovation: The new imperative for creating and profiting from technology*. Boston: Harvard Business Scool Press.

Duffus, J. H. (2002). "Heavy metals"—a meaningless term? (IUPAC Technical Report). *Pure Appl. Chem., 74*(5), 793–807. Also available at http://www.szennyviztudas.bme.hu/files/iupac%20heavy%20metals.pdf

Fausto, S., & Mena-Chalco, J. (2015). *Leadership among the leaders of the Brazilian research groups in marine biotechnology*. ISSI Conference paper 814-815. DOI: 10.13140/RG.2.1.1800.5607

Group on Earth Observation (GEO). (2009). *Strategic Targets: GEOSS Implementation by 2015*. Geneve: GEO.

Golden Rice Humanitarian Board (2016). *Golden rice project*. Retrieved from http://www.goldenrice.org/Content1-Who/who4_IP.php

González, E., Marrugo, J., & Martínez, V. (2015). *The problem of mercury contamination. Nanotechnology: Challenges and possibilities for measurement and remediation* (*El Problema de contaminación por Mercurio. Nanotecnología: Retosy posibilidades para medición y remediación)*. Bogotá: Red Nano Colombia.

Hautea, R., & Cruz, M. V. (2007). *New generation GM/Biotech crops* (APSA Technical Report 47). Philippines: International Service for the Acquisition of Agri-biotech Applications (ISAAA). Retrieved from http://apsaseed.org/index.php/publications/publications-for-members/techical-reports/27-tr-no-47-new-generation-gm/file

Hautea, R., & Escaler, M. (2004). Plant biotechnology in Asia. *AgBioForum, 7*(1&2), 2-8.

Inter-American Development Bank. (2015). *Rethinking productive development: Sound policies and institutions for economic transformation*. Retrieved from https://publications.iadb.org/handle/ 11319/6633

Jamier, V., Varón, M., González, E., & Puentes, V. (2012). Designed synthesis of nanoparticles for a sustainable world. *Nanotechnology Perceptions, 8(3)*, 205-214.

Jarvis, S., & Richmond, N. (2011). Regulation and governance of nanotechnology in China: Regulatory challenges and effectiveness. *European Journal of Law and Technology, 2*(3), 1-11.

Meyer, T. (2013). Epistemic institutions and epistemic cooperation in international environmental governance. *Transnational Environmental Law, 2*(1), 15-44.

Ministerio de Ambiente y Desarrollo Sostenible. MINAMBIENTE. (2016). *Ministerio de ambiente y desarrollo sostenible de la República de Colombia*. Retrieved on January 2016, https://www.minambiente.gov.co/index.php/component/content/article?id=1613:el-uso-sostenible-de-los-bosques-prioridad-de-minambiente-763

National Science and Technology Council Committee on Technology. (2014). *National nanotechnology initiative strategic plan*. Retrieved from http://www.nano.gov/sites/default/files/pub_resource/ 2014_nni_strategic_plan.pdf

Organization for Economic Cooperation and Development (2012). *Meeting global challenges through better governance: International co-operation in science, technology and innovation*. OECD Publishing. Retrieved from http://dx.doi.org/

10.1787/9789264178700-en
Organization for Economic Cooperation and Development (OECD). (2013). *Innovation in Southeast Asia*. Paris: OECD Publisihing. DOI: 10.1787/19934211
Organization for Economic Cooperation and Development/Economic Commission for Latin America and the Carribean/ Cor poracion Andina de Fomento (OECD/ECLAC/CAF). (2015). *Latin American economic outlook 2016: Towards a new partnership with China*. Paris: OECD Publishing. Also available at http://www.oecd.org/publications/latin-american-economic-outlook-20725140.htm
Organization for Economic Cooperation and Development/United States National Nanotechnology Initiative (OECD/NNI) (2013). *Symposium on assessing the economic impact of nanotechnology: Synthesis Report*. Retrieved from https://www.oecd.org/sti/nano/Washington%20Symposium% 20Report_final.pdf
Payumo, J., & Sutton, T. (2015). A bibliometric assessment of ASEAN's output, influence and collaboration in plant biotechnology. *Scientometrics, 103*(3), 554-559.
Pearce, J. (2013). Open-source nanotechnology: Solutions to a modern intellectual property tragedy. *Nano Today, 8*(4), 339-341.
RELX Group. (2016). *Scopus*. Retrieved on February 2016 from http://www.elsevier.com/online-tools/scopus
Roco, M. (2005). International perspective on government nanotechnology funding in 2005. *Journal of Nanoparticle Research, 7*(6), 707-712.
Sawada, Y., Matsuda, A., & Kimura, H. (2012). On the role of technical cooperation in international technology transfers. *Journal of International Development, 24*(3), 316-340.
Search Technology Inc. (2016). *Vantage point*. Retrieved on February 2016 from https://www.thevantagepoint.com/
Stiglitz, J. (2012, May 18). A breakthrough opportunity for global health. *Project syndicate*. Retrieved from https://www.project-syndicate.org/commentary/a-breakthrough-opportunity-for-global-health?barrier=true
Stiglitz, J., & Greenwald, B. (2014). *Creating a learning society: A new approach to growth, development and social progress*. New York: Kenneth J. Arrow Lecture Series.
Tang, L., & Shapira, P. (2011). Regional development and interregional collaboration in the growth of nanotechnology research in China. *Scientometrics, 86*(2), 299-315.
Thomson Reuters. (2016). *Thomson innovation*. Retrieved on February 2016 from http://www.thomsoninnovation.com
World Intellectual Property Organization (WIPO) (2016). *Transfer of technology*. Retrieved on February 2016 from http://www.wipo.int/patents/en/topics/technology_transfer.html