J Agric Environ Ethics (2014) 27:681–694
DOI 10.1007/s10806-014-9502-2

REVIEW PAPER

Environmental Biotechnology Research: Challenges and Opportunities in Latin America

Janeth Sanabria

Accepted: 9 April 2014 /

Abstract Latin American countries have an extensive biological diversity and a tropical or subtropical climate. This condition has advantages for development and for the implementation of biotechnological solutions for environmental problems. Environmental biotechnology could be used to enhance biodegradation, waste recovery, and also for the development of biotechnology-based products to diagnose and reduce environmental impacts such as biosensors, biopesticides, biofertilizers and biofuels. To generate new environmental biotechnological products, Latin American countries must not only overcome the known limitations associated with investment in science and technology and in human resource training, but also develop their own vision of using environmental biotechnology, adapted to the economic, and environmental context. Biotechnology used wisely as a tool for promoting sustainable development in Latin American countries may also contribute to the solution of problems that represent potential risks to society and the environment in general. This document discusses the context of the research and innovation in Latin American countries around environmental biotechnology and also reviews perspectives for the improvement of these developments.

Keywords Environmental biotechnology · Microbial diversity · Reactors · Contamination · Sustainability · Policies

Introduction

The term “environmental biotechnology” has been coined to describe the use of biological systems, ranging from bacteria to plants, to achieve environmental

---

J. Sanabria (✉)
Laboratory of Environmental Microbiology and Biotechnology, Research Group on Advanced Processes for Chemical and Biological Treatments, Universidad del Valle, Cali, Colombia
e-mail: janeth.sanabria@correounivalle.edu.co

remediation, pollution prevention, detection and monitoring of contaminants and more recently transforming waste to produce energy, bio-polymers and others benefits (Maroušek et al. 2013b). When a natural ecosystem is polluted, the treatment process is referred to as bioremediation, or in situ bioremediation. When the pollutant is treated "end of pipe", the process is termed biotreatment or ex-situ bioremediation (Ivanov et al. 2010). In Latin America, bioremediation has traditionally targeted readily organic matter. Today, environmental biotechnology focuses on more challenging pollutants, like micro pollutants, greenhouse gases, heavy metals, dyes, etc. Due to advances in molecular biology and biochemical methods, knowledge of the ecological, genetic, and metabolic diversity of organisms and their use for bioremediation have had seen considerable advances. For example, in phyto-remediation processes, the use and acquisition of organisms, or their enzymes, in the efficient transformation of a pollutant (Maroušek et al. 2013a); the treatment of pesticides and nutrients, the generation of environmentally friendly products, and the production of bio-fuels. Furthermore, the coupling of technologies has been credited with achieving an enhanced performance of biological systems. (Mora et al. 2005; Sanabria et al. 2010; Li et al. 2014). Progress in the understanding of microbial diversity along with the use of molecular techniques and the development of new diagnosis methods have opened a new range of alternatives for research and innovation in systems and treatment processes (Divakara et al. 2010; Dunlop et al. 2011). In spite of this progress of research around the world, the development and operation of innovative technologies to solve Latin Americas environmental issues are incipient, and a common strategy is the usage of scaled systems that have been developed and patented in developed nations. A direct connection may be seen between these conditions and the comparatively low level of private and public investment in science and technology, in particular regarding those investments and care for the environment and therefore resulting in a disappointing perspective for innovation in environmental biotechnology. In this sense, productive processes (Voget-Kleschin 2013), and government policies must include, as a prerequisite, environmental sustainability in the process of turning current societies into green societies, as well as minimizing waste and emissions plus processes on making the most of product output.

Research and development centers can be an effective organizational space where researchers and the manufacturing productive sector can find innovative ways for effective care for the environment. This paper compares the most representative countries in Latin America as well as highlighting some of the difficulties behind this approach describing opportunities in which researchers in environmental biotechnology could achieve technological innovation and scientific global competitive quality in the region.

The Context of Environmental Biotechnology

Among the environmental discussions occupying governments throughout the world in recent years, global warming, nutritional safety, the water supply, and the reduction of infectious diseases stand out. In the case of greenhouse gases, the objectives are focused on the reduction of nitrogen oxides, CO_2, CH_4, N_2O and ozone; with CO_2 and CH_4 in the spotlight because of the volumes in which these are produced (Patterson 2012), both the increasing demand for water resources (in intensive livestock operations and human consumption), and the high cost of treatment (due to the contamination of surface and groundwater sources), result in an increased cost for populations to have access to drinking water, and in incidence the rate of water-borne diseases.

With the implementation of environmental protection legislation in some countries, the setting of standards for industry and the enforcement of compliance; environmental biotechnology grew in importance in the 80s. This has motivated the search for clean production processes (diminished wastes and reuse), thus minimizing the use of harmful fertilizers, herbicides, and fungicides. In contrast to most developing countries, there is no information on the quantities, location, and effect of important pollutants like micro pollutants, pesticides and nutrients. Political priorities in Latin America must continue with industry and commerce and those are activities which are not associated with caring for the environment. We could cite, as a striking example, the fact that from the total of wastewaters produced in Colombia, only 25 % is treated to remove organic compounds (Ministerio de Ambiente 2010). Meanwhile norms to control the emission of nutrients, micro-pollutants and toxic compounds are rarely included, meaning that real action to protect the environment and ensure for public health is minimal. The increasing occurrence of diseases like cholera has been related to a decline in water quality (Ramamurthy et al. 2011).

Different studies on biotechnology competence in Latin America (including projects, qualified human resources, laboratories, etc.) recognize the importance of biotechnology and thereby, the necessity for raising public and private investments and improving human capacity (Bota 2003; Roca 2003; Leff 2012). In this sense, some countries (Brazil, Mexico, Argentina) have made great efforts to increase investment in science and technology including Biotechnology. Unfortunately, these same studies show that only a fraction of these efforts is focused on topics related directly to the protection of the environment. This may be due to a lack of knowledge of the actors of environmental Biotechnology, their characteristics and benefits. As an illustration, Fig. 1 shows publications from the last ten years in Brazil and Colombia in environmental areas as an indicator of these phenomena. Within this context the use of biotechnology represents 45–50 % of research registered in environmental areas for Colombia and Brazil respectively. This is evidence that from the total of published research, in the environmental issues it does not exceed 3 %, despite differences of investment in science and technology in those countries with Brazil at nearly 1, 2 %, and Colombia 0.18 % of Gross National Product, (World Bank 2014) Similar results were obtained for other Latin American countries. It is clear that, while there are no policies to control environmental pollution, natural resources will continue to deteriorate with negative consequences to both the economy and to public health for these regions.

Innovation Opportunities in Environmental Biotechnology

The latest generation biotechnology or recombinant DNA biotechnology with the genetic alteration of living organisms is the most accepted definition for Biotechnology

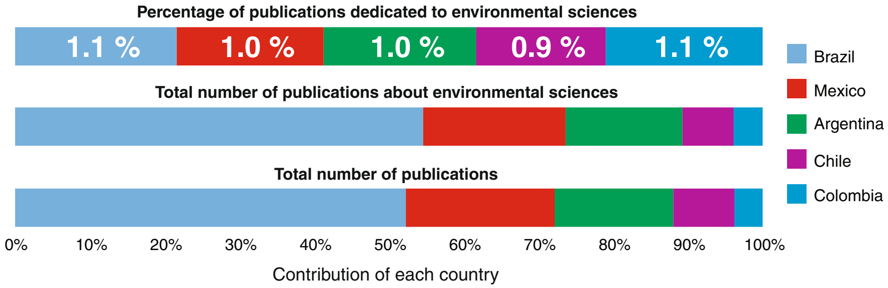

Fig. 1 The bottom and middle bar reports the productivity of each countries as fractions of the total number of publications and the total number of publication in environmental sciences, while the top bar shows that the percentage, in superimposition, of publication in environmental sciences with respect to the total of publication for each country is similar; search criteria: bioremediation OR environmental or Biological treatment. (*Source*: SCOPUS, August 2014)

in Latin America. With recombinant DNA technology, the scientist can introduce a gene sequence that confers a feature within an organism, creating a genetically modified organism (GMO). Nevertheless, there is an intrinsic limitation for this modification in environmental biotechnology because natural competence like predations and other extreme environmental conditions. In this sense the practice remains the adaptation of what exists in the gene pool of biosystems in real conditions. For decades, the development of biological treatment systems focused on easily degradable organic compounds present in wastewater effluents and in solid wastes. In these cases, most of the attention was aimed at designing systems to remove these compounds with high efficiencies. Most of these technologies were developed and improved in developed countries and were brought to Latin America, without adapting them to local conditions. Meanwhile, new demands arose worldwide for the treatment and diagnosis of new forms of contamination, such as pesticides, heavy metals, colorants, liquid phase and volatile cyclic organic compounds (VOCs), drugs and their by-products, etc., (Gavrilescu 2010). In most Latin American countries, these pollutants are discharged into the environment without any treatment. Both bioremediation and the latest generation biotechnology could be used to contribute to solve environmental problems and obtained value products. The key to successful bioremediation is to harness the naturally occurring catalytic capability of microbes to transform environmental pollutants. Using the potential of biodiversity, the study of ecological adaptation of bacterial consortia and the use of genomic, proteomic, metabolomics, and computational techniques as well as the generation of micropollutant sensors, will give rise to reliable and innovative options for cheaper decontamination. Most Latin American countries are located in the tropical zone, with warm climates, and high biodiversity. Temperature and diversity are two well-known limiting conditions in biological systems, while also proving to be a comparative advantage in technologies using bioprocesses. Researchers could include bioprospecting, as a way of addressing these problems by seeking support for new discoveries and technological enhancement for topics such as: (1) the treatment of liquid and solid wastes using the potential of tropic biodiversity; (2) use of the advantages of solar

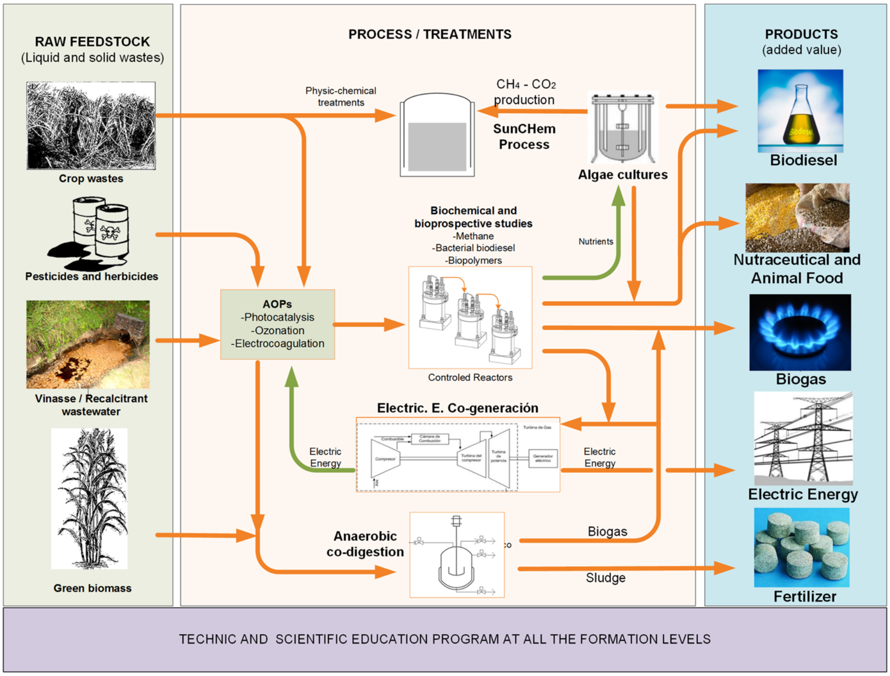

Fig. 2 Scheme of sugar cane industry waste valorization using solar energy and biotechnological systems

energy sources to coupling new disinfection and decontamination alternatives (3) definition and development of new bioindicators for pollution; (4) study of emerging microorganisms and their relationship with public health; (5) recovery and value of waste, transforming it into clean energy and nutrients using technological clusters. An example is shown in Fig. 2.

From Diversity to Microbial Adaptation

One of the advantages for innovation in tropics is biodiversity. Different studies have clearly demonstrated that both, diversity of animals and plants, are greater at lower latitudes. Despite the fact that there are only a few studies that allow the comparison of an ecological index of prokaryotic diversity by regions in the planet, it is not difficult to think of the tropic as a zone which equally favors this natural microbial diversity therefore microbial metabolic processes in the tropics are substantially higher in rate. The methods to estimate the prokaryotic diversity in natural environments has experienced vast changes. The use of molecular and fluorescence techniques has led to changing the consideration of diversity assessed with culture methods from hundreds of species at an estimated values of 10^{29} (Christen 2008).

The structural complexity of environments is important for speciation; likewise, it is known that disturbances of natural environments favor the conditions for the establishment of new species or metabolic adaptation (Martins et al. 2013). The environmental engineer practice recommended the use of pre-adapted sludge to start a new bioreactor and this practice has promoted for many years a separation of organisms that probably generates speciation, certainly not yet explored and potentially usefully for environmental solutions. Greater biological diversity represents greater options of unexplored biochemical opportunities in the tropics (Pérez-Peláez et al. 2011). In this sense, bio-prospecting studies being conducted in extreme natural environments must be broadened to include contaminated environments and treatment systems but, above all, feedback must be provided with results and requirements from the groups and sectors developing applied research. The step from anticipation to application will require innovative strategies to culture the non-culturable from natural or constructed environments (culture targeted-bioprospeting). Although little information was found in literature regarding microorganism culture methods from treatment systems, the recent anammox culture can be cited as a good example of a mechanism that enriches bacteria without isolation as a pure bacteria (Liao et al. 2007).

Challenges in Microbiology Applied to Environmental Solutions in Latin America

Treatment Systems: Biotreatment/ex situ bioremediation are almost typical end-of-pipe processes applied to remove, degrade, or detoxify pollution using different process (biodegradation and bio-transformation, immobilization), systems are reactors, open constructed wetlands, ponds, soil filters, land farming, composting and biopiles, in which the decontaminating process takes place. *Classical bioremediation*/in situ bioremediation involves treating the contaminated material at the site, using processes like phytoremediation, bioventing, bioleaching, land farming, bioaugmentation, rhizofiltration, and bio stimulation. Biodegradation is carried out by consortia of microorganisms. To be more efficiently removed, the pollutant must be the main electron donor or carbon source for the organisms present. In ecological terms, we find that bio-treatment systems are eutrophic ecosystems. In such systems, the different trophic levels of living organisms are established and affected by design conditions, especially the hydraulics (for liquid and gaseous pollutants), chemical composition, solubility and quantity also play an important role. Open bio-treatment systems will also be affected by environmental conditions such as rain, temperature changes and wind. As a general rule, the microbial groups that predominate in such systems are capable of "naturally" adapting to these conditions. Hence the challenge for bio-technologists is to accomplish high-performance microbial adaptations under these extreme conditions and/or to give the microorganisms a better substrate without increasing treatment costs, or to recover them through waste assessment. It seems that in such critical conditions the best solution might be to use more than one piece of technology like biorefinery. Wastes valorisation to obtain added-value from controlled artificial systems by the production of enzymes and other metabolic by products founded in these systems can mitigate the high cost of the technologies implied.

The dynamics of microbial ecology or microorganisms present in bio-remediation systems has not been broadly studied. We consider there are reasons for this, other than the general reasons already mentioned, associated with the research context which we highlight based on our experience:

- Basic knowledge of biological processes and even a lack of knowledge of such (black box) processes has allowed engineers in the region, until a few years ago, to develop technologies capable of satisfying the demand of the established norms (focused on chemical oxygen demand -COD) and because of the poor control and flexibility of environmental norms for treatment. Flexibility in regulations aimed at controlling nutrients and micro pollutants released into wastewaters in Latin America have been leading to an environmental deterioration.
- There is a separation between the development of research in microbiology, chemistry, and engineering, which are three of the most important areas in environmental biotechnology. Also, there is the need to focus the science and technology development to solve local and social problems in a interdisciplinary manner. In other words, there has been serious work on collaborative and interdisciplinary projects but in Latin America there is not such a culture of cooperation; for instance, Brazil should lead cooperation between developing countries nearby. Some groups address interdisciplinary collaboration through bibliographic consultation but this is also limited, both by the restricted access to data bases and by their limited mastery of English; both of which are still privileges for only a few institutions and individuals in the region.
- Many microbiological methods are expensive and wasteful in their routine use in control and research of the so-called special pollutant biodegradability and the technical capacity of laboratories does not respond to these new necessities.
- Only recently some microbiological methods adapted for environmental microbiology (epifluorescence and confocal microscopy, cytometry, genomic, proteomic, micro-kinetics, biochemical markers, and adaptation of culture methods, among others) were introduced into some countries in Latin America therefore enabling the study and use of previously unknown microorganisms. Furthermore, we must ask ourselves what are the appropriate analytical methods that permit quantifying the microbiological activity in waste. The most sophisticated methods do not always provide us with the most useful information. For instance, knowing all the microbial species present in a treatment system will not necessarily help us to determine which group is the most representative for the process (Watanabe et al. 2002). Recently, molecular methods that might be useful in studying diversity have been developed; however, many of these methods are not quantitative for microbial activity and, thus, yield scant information concerning the optimization of design and operation of treatment systems, probably studying the proteins expressed in the reactors could be most useful. We must wonder, when the study of diversity help to improve a biological treatment system? In this sense the work about main

questions and answers must be done before the choice of molecular methods for molecular studies.

Many approaches in biodegradation research considers the fact that pollutants normally do not appear in pure form but as mixtures, under different concentrations, pH conditions and temperature, and this has effects on microorganisms and their activities (Oren et al. 2010), therefore the researchers community must propose strategies to:

1. Improve and develop alternative biological packages that combine biotechnology with other treatment forms and advanced physical and chemical processes. This implies a dialogue among disciplines like microbiology, biochemistry, biotechnology, and engineering, which cannot be delegated.
2. Guide and place the results of bio-prospecting organisms with potential at the service of environmental applications focused on real problems.
3. Study and model the biochemical behaviour of ecosystems with biotechnological potential to develop innovative products that could be applied to the solution of specific environmental problems.
4. Adapt ecological competence of microorganism consortia, to innovative culture systems. The most recent studies to improve culture methods have revealed that microbial associates are the key to the development of many microbial populations (Vázquez et al. 2013). These new culture methods must consider this association to improve pollution degradation.
5. Introduce an integral approach in what has been denominated as an analysis of systems. This will be key for future progress on bio-remediation because in environmental biotechnology, more than in any other branch of biotechnology, the study of a separate species and technology may be insufficient to understand the biodegradability and to propose an efficient process for the treatment of a pollutant. An example we could cite to illustrate this point are the efforts made by microbiologists to adapt and genetically transform microorganisms in order to increase their capacity to biodegrade dyes and pesticides. Meanwhile, research groups focusing not only on microorganisms but also on pollutants have managed to develop technologies based on solar radiation, the ozone, electro-chemistry, and chemical catalysts to convert complex pollutants into simpler ones with higher a probability of biodegradation.
6. Develop reliable molecular and analytical diagnostic methods. Overcoming the limitations of the compounds present in waste given that they often interfere in the measurement and yield incorrect results.

Environmental Biotechnology Products

One of the relevant aspects of defining biotechnology is its relationship to obtain goods or services suitable for being commercialized and generating profit. Understanding biotechnology in a complex and in realistic terms implies tangible and intangible investments. This applies to domestic as well as foreign imported technologies and knowledge. Each country has to exert considerable absorptive efforts to learn the tacit elements of biotechnology and gain adequate mastery.

By itself, conducting good environmental control implies investments without apparent return for private and public companies. This fact has limited the development of research because of the low interest to invest in caring for the environment. The criteria of decreased costs and profit make it difficult to find support for environmental biotechnological products (Beekman 2004; Liguori et al. 2013). This aspect has motivated organizations like the United Nations Environment Program (UNEP 2010) to insist on the introduction of accounting factors associated to environmental deterioration, encourage treatment processes and elimination of wastes under safer conditions, and strengthen legislation to control pollution. It has been calculated that contamination of coastal waters by sewage provokes 250 million cases of gastroenteritis, the loss of millions of lives (mostly children under 5) throughout the world, and an economic loss of 16 billion US dollars annually (UNEP 2010). Hence, interest in the region is concentrated on the development of treatment systems with low investment costs and, whenever possible with added economic value. Regarding biotreatments, we consider that anaerobic systems offer the special advantage of diminishing operation costs through the injection of oxygen and the disposition of generated sludge, while methane, bio-hydrogen, and raw materials for other value products are generated and new species are described. Also, the use of "constructed wetlands and ponds" can favor the recovery of nutrients in the form of vegetable biomass. One of the most promising advances in solid and liquid waste assessment is the acquisition of second-generation biofuels (Lino and Ismail 2011). Although the global tendency favors alcohols, we believe bio-hydrogen, methane, bio-diesel and bio-polymers adjust best to local needs, environmental conditions, and to Latin America's research capacity (De Sá et al. 2013). As an other example we can cite the recently discovery of Nitrogen fixation in wastewater systems adapted to a large amount of Anomia (Pérez-Peláez et al. 2011; Abramovich 2013). The availability of a vast amount of information has placed in the foreground bioinformatics and in silico research because of its potential to lower costs of experimentation.

Figure 3 shows a comparison of 10 of last year's publications in the most representative countries in Latin America regarding the biotechnological products previously mentioned. The first interesting aspect we found is that Brazilian publications account for more than 50 % of the total in Latin America, followed by Mexico and Argentina. Related with the topic of publication we found that, while Brazil research emphasizes on biosensor, biopolymer and biofuel from wastes, research in Mexico focuses on treating atmospheric pollutants and using biofiltration, aerobic treatments and in situ bioremediation. Argentina reports an important number of publications for biosensor research and coupling between advanced oxidation processes and biological systems. Chile has focused their publications on aspects concerning bio-filtration, advanced oxidation processes and aerobic treatments. From the consulted countries Colombia and Venezuela report the fewest of publications on environmental biotechnology topics consulted in this study, (<7.3 and 2.8 % respectively). Colombia has emphasized its research on constructed ponds and wetland, bio-insecticides, anaerobic treatment and the use of advanced oxidation processes coupled with biological treatment. A combination of

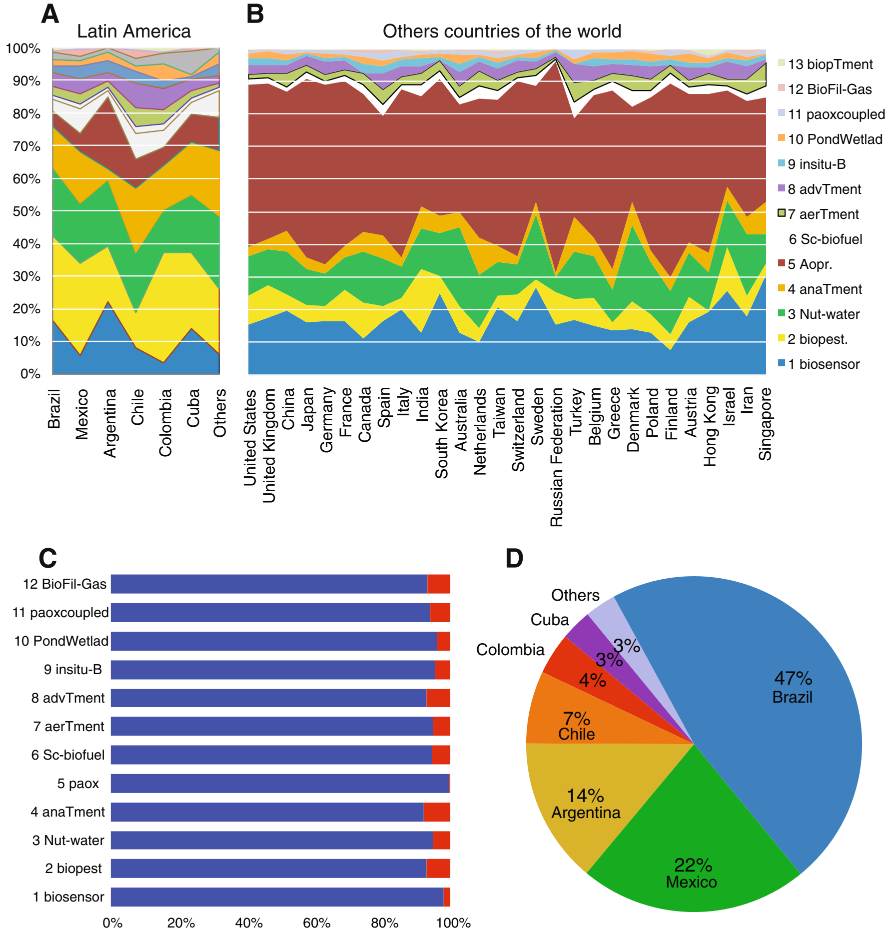

Fig. 3 **a** Comparative tendency of the publication in environmental biotechnology in Latino-America and the rest of the world. **b** Comparative publication for Latino American countries in Latino-America and the rest of the world. **c** Comparative publication in environmental areas between Latino American countries.Search criteria of each area: *1* (biosensor); *2* (thuringiensis OR sphaericus OR metharizium OR beauveria AND biopesticides); *3* (Treatment AND Nitrogen OR Phosphorus AND Water); *4* (anaerobic AND wastewater AND treatment); *5* (waste AND treatment AND ethanol OR methane OR biohydrogen); *6* (aerobic AND wastewater AND treatment); *7* (electrocoagulation OR ozone OR photocatalysis); *8* (micropollutant OR cebiotic OR advanced treatment OR thertyary treatment AND Water). *9* (soil OR river OR see AND bioremediation AND treatment) *10* (constructed ponds OR constructed wetland and treatment); *11* (electrocoagulation OR ozone OR photocatalysis AND biological treatment); *12* (biofiltration OR gas) *13* (biopolymer OR PHAs AND waste). Others (Venezuela, uruguay, Costa rica, Ecuador, Guatemala, Dominican Republic, Nicaraguas, Panamá, Paraguay, Perú, Puerto Rico). SCOPUS J 2014

anaerobic pre-treatment followed by photosynthetic post-treatment is proposed for the effective recovery of energy and nutrients from sewage. Similar tendency to those from Scopus database have been obtained using the Scielo database, and data obtained from the World Bank report as shown in Table 1.

Table 1 Most recent value: science and technology indicators for Latin-American Countries

Country	Total people[a]	Total research product[b]	Total economical products[c]	% of GDP[d]
Brazil	1,361	187,727	12,601.7	1.16
México	623	118,464	42,027.5	0.4
Argentina	1,312	78,802	4,444	0.6
Chile	648	55,770	1,437.6	0.37
Colombia	161	31,645	1,022.3	0.16
Perú	ND	26,038	532.2	ND
Paraguay	75	22,478	53.3	0.06
Venezuela, RB	183	21,539	453.5	ND
Ecuador	137	16,957	126.2	0.26
Costa Rica	334	14,866	2,642.8	0.54
Panamá	117	11,886	4,858.4	0.19
Guatemala	56	9,528	286.4	0.06
Uruguay	520	7,235	118.8	0.43
Dominican Republic	ND	6,459	163.2	ND
Cuba	ND	2,509	ND	0.61
Honduras	ND	2,258	52.3	ND
Haiti	ND	1,956	8	ND
Bolivia	181	45	113.7	0.16
Nicaragua	ND	12	12.3	ND
El Salvador	ND	6	250.8	0.08
Puerto Rico	668	ND	ND	0.49

Science and technology World Development Indicators 2013, THE WORLD BANK Last updated date 09/23/2013 (N) if data for the specified year or full period are not available

[a] Researchers, Technicians Scientific and technical (full-time equivalent per million people) 2005–10

[b] Journal articles Patent (Residents Nonresidents) applications filed Trademark, applications filed Expenditures for R&D

[c] High-technology exports, Charges for the use of intellectual property $ millions

[d] % of GDP 2005–10

Educational and Training Challenges

One of the challenges is that it involves learning professional skills. Some reports on biotechnology capabilities consider that the skills are learned in college. Some countries Mexico, Brazil, Chile and Argentina have increasing research and training around biotechnology. However, there is currently a tendency to view learning about problem solving takes place during the early years of school. This learning has a greater impact than what you can learn in college. University should be the space in which students polish such skills in the context of a particular problem. A recent diagnosis in Chile demonstrated that the media and high school learning are more responsible for development skills than universities in the future of professionals. Additionally the latest report from the OECD PISA on the skills of students aged 15 years, shows the critical situation in Caribbean countries in reading and mathematics (OECD 2014). This report can also infer the relationship between the quality of secondary education and development. Taking the example of China and Korea, a notable policy in these countries is introducing massive programs to improve the participation of professionals who can link between technical and social, ecological and environmental contexts and English language skills. In addition to these general considerations, we find particular aspects to be considered. The modernization of biochemistry teaching at all levels of scholarship is a priority. The revisions of programs in the region suggest that the biochemical training in environmental engineering, biology and bacteriology carrier is limited. Prevalent subjects include biochemistry of sugars, lipids, proteins, heterotrophic aerobic metabolism, due probably to the overwhelming influence of medicine in teaching biochemistry. New approaches for biochemical training must include, the link between these biochemical conditions with others like litotrophic phenomena, anaerobic metabolisms, Bioenergy, thermodynamics, microbial ecology, stoichiometry and kinetic involved in it. The compulsory introduction of interdisciplinary components in engineering and basic science programs is necessary. Nevertheless only technical educations are not sufficient to build a new sustainable society. Analyses and characterize critical environmental problems, put forward and execute solution proposals for the identified environmental problems, do research and teaching in multidisciplinary groups and manage a diverse discourse, is maybe the most important educational challenge.

Table 1 shows the importance to invest in Research and Development (GDP percentage), over the qualified personal in Science Technology and the scientific products as well.

Conclusions

Despite differences in the historical development of science and technology in Latin American countries. There has been an increase in spending on science technology and training. Caring for the environment has been neglected in most countries due to the apparent cost that entails. However, in the situation of the world environmental crisis and wealth of biodiversity as well as the climate in most parts of Latin America, we are located in a privileged site to develop ingenious and sustainable alternatives in Environmental Biotechnology. To achieve this goal we need to be aware of global progresses but propose our creative approaches, considering different ways that have been so far shown promising, thereby breaking the linear vision of basic science—applied science—innovation. Changing policies proposed by the support of science and technology only in its advanced stages and recovering the creative intuition from our childhood.

Acknowledgments To Dr Huub Hitzen from the UNESCO-IHE for important contributions to this paper. And my colleagues of the engineering faculty by give me the opportunity of learning about environmental engineering. The author thanks Luis Andrés Betancourt and Julien Wist for their invaluable contribution to graphical material.

References

Abramovich, R. S. (2013). Nitrogen fixing potential in extreme environments. In *School of biotechnology and biomolecular sciences*. University of New South Wales Sydney, Australia. p. 241.

Beekman, V. (2004). Environmental utilization space between science and politics. *Journal of Agricultural and Environmental Ethics, 17*, 293–300.

Bota, A. A. (2003). El impacto de la biotecnología en America Latina: Espacios de participación social. *Acta Bioethica, 9*, 21–38.

Christen, R. (2008). Global sequencing: A review of current molecular data and new methods available to assess microbial diversity. *Microbes and Environments, 23*, 253–268.

De Sá, L. R. V., Cammarota, M. C., De Oliveira, T. C., et al. (2013). Pentoses, hexoses and glycerin as substrates for biohydrogen production: An approach for Brazilian biofuel integration. *International Journal of Hydrogen Energy, 38*, 2986–2997.

Divakara, B. N., Upadhyaya, H. D., Wani, S. P., et al. (2010). Biology and genetic improvement of *Jatropha curcas* L.: A review. *Applied Energy, 87*, 732–742.

Dunlop, M. J., Dossani, Z. Y., & Szmidt, H. L. et al. (2011). Engineering microbial biofuel tolerance and export using efflux pumps. *Molecular Systems Biology*, *7*(1). doi:10.1038/msb.2011.21.

Gavrilescu, M. (2010). Environmental biotechnology: Achievements, opportunities and challenges. *Dynamic Biochemistry, Process Biotechnology and Molecular Biology, 4*, 1–36.

Ivanov, V., Wang, L. K., Ivanov, V. et al. (2010). Microbiology of environmental engineering systems. In *Environmental biotechnology. Handbook of environmental engineering*. Humana Press, pp. 19-79-79.

Leff, E. (2012). Pobreza, gestión participativa de los recursos naturales y desarrollo sustentable en las comunidades rurales del Tercer Mundo. Una visión desde América Latina. *Problemas del Desarrollo, 26*, 223–240.

Li, T., Guo, S., Wu, B. et al. (2014). Effect of polarity-reversal and electrical intensity on the oil removal from soil. *Journal of Chemical Technology & Biotechnology*. doi:10.1002/jctb.4312.

Liao, D., Li, X., Yang, Q., et al. (2007). Enrichment and granulation of Anammox biomass started up with methanogenic granular sludge. *World Journal of Microbiology & Biotechnology, 23*, 1015–1020.

Liguori, R., Amore, A., & Faraco, V. (2013). Waste valorization by biotechnological conversion into added value products. *Applied Microbiology and Biotechnology, 97*, 6129–6147.

Lino, F. A. M., & Ismail, K. A. R. (2011). Energy and environmental potential of solid waste in Brazil. *Energy Policy, 39*, 3496–3502.

Maroušek, J., Itoh, S., Higa, O., et al. (2013a). Enzymatic hydrolysis enhanced by pressure shockwaves opening new possibilities in *Jatropha Curcas* L. processing. *Journal of Chemical Technology and Biotechnology, 88*, 1650–1653.

Maroušek, J., Kondo, Y., Ueno, M., et al. (2013b). Commercial-scale utilization of greenhouse residues. *Biotechnology and Applied Biochemistry, 60*, 253–258.

Martins, L. F., Antunes, L. P., Pascon, R. C., et al. (2013). Correction: Metagenomic analysis of a tropical composting operation at the São Paulo Zoo Park reveals diversity of biomass degradation functions and organisms. *PLoS ONE, 8*, 1–13.

Ministerio de Ambiente VyDT-M (2010). *Política Nacional para la Gestión Integral del Recurso Hídrico*. Bogotá, D.C. Colombia. Ministerio de Ambiente, Vivienda y Desarrollo Territorial-MAVDT. p. 124.

Mora, L. E., Colina, J., & Moncayo-Lasso, A. et al. (2005). Development of coupled solar biological system for the disinfection and elimination of organic contaminants in drinking water in rural areas of Colombia. In CINARA (ed) *De la accion local a las metas globales*. CINARA, Cali Colombia. pp. 1–8.

OECD (2014). PISA 2012 Results: What students know and can do: Student performance in mathematics, Reading and Science (Volume I), http://www.oecd.org/pisa/keyfindings/pisa-2012-results-volume-i.htm access 30 mars 2014.

Oren, A., Wang, L. K., Ivanov, V. et al. (2010). Microbial metabolism: Importance for environmental biotechnology. In *Environmental biotechnology. Handbook of environmental engineering*. Humana Press, pp. 193-255-255.

Patterson, J. (2012). Exploitation of unconventional fossil fuels: Enhanced greenhouse gas emissions. In Liu, G. (Ed.)*Greenhouse gases—emission, measurement and management.*. InTech. pp. 147–168.

Pérez-Peláez, N., Peña-Varón, M., & Sanabria, J. (2011). Comunidades bacterianas involucradas en el ciclo del nitrógeno en humedales construidos. *Revista Ingeniería y Competitividad, 13*, 11–17.

Ramamurthy, T., Bhattacharya, S. K., Delgado, G. et al. (2011). The re-emergence of Cholera in the Americas. In *Epidemiological and molecular aspects on cholera. Infectious disease*. New York: Springer pp. 79-95-95.

Roca, W. (2003). Estudio de las capacidades biotecnológicas e institucionales para el aprovechamiento de la biodiversidad en los paises de la comunidad Andina, Peru. pp. 285.

Sanabria, J., Acevedo, D., Morales, M., et al. (2010). *Improvement of methane production using photo-Fenton as pretreatment of vinasses*. Manizales, Colombia: Congreso Iberoameicano de Biotecnología.

UNEP (2010). Annual Report 2009: Seizing the green economy UNEP.

Vázquez, S., Nogales, B., Ruberto, L., et al. (2013). Characterization of bacterial consortia from diesel-contaminated Antarctic soils: Towards the design of tailored formulas for bioaugmentation. *International Biodeterioration and Biodegradation, 77*, 22–30.

Voget-Kleschin, L. (2013). Large-scale land acquisition: Evaluating its environmental aspects against the background of strong sustainability. *Journal of Agricultural and Environmental Ethics, 26*, 1105–1126.

Watanabe, K., Futamata, H., & Harayama, S. (2002). Understanding the diversity in catabolic potential of microorganisms for the development of bioremediation strategies. *Antonie van Leeuwenhoek, 81*, 655–663.

World Bank (2014). Research and development expenditure (% of GDP) http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS/countries access 30 mars 2014.