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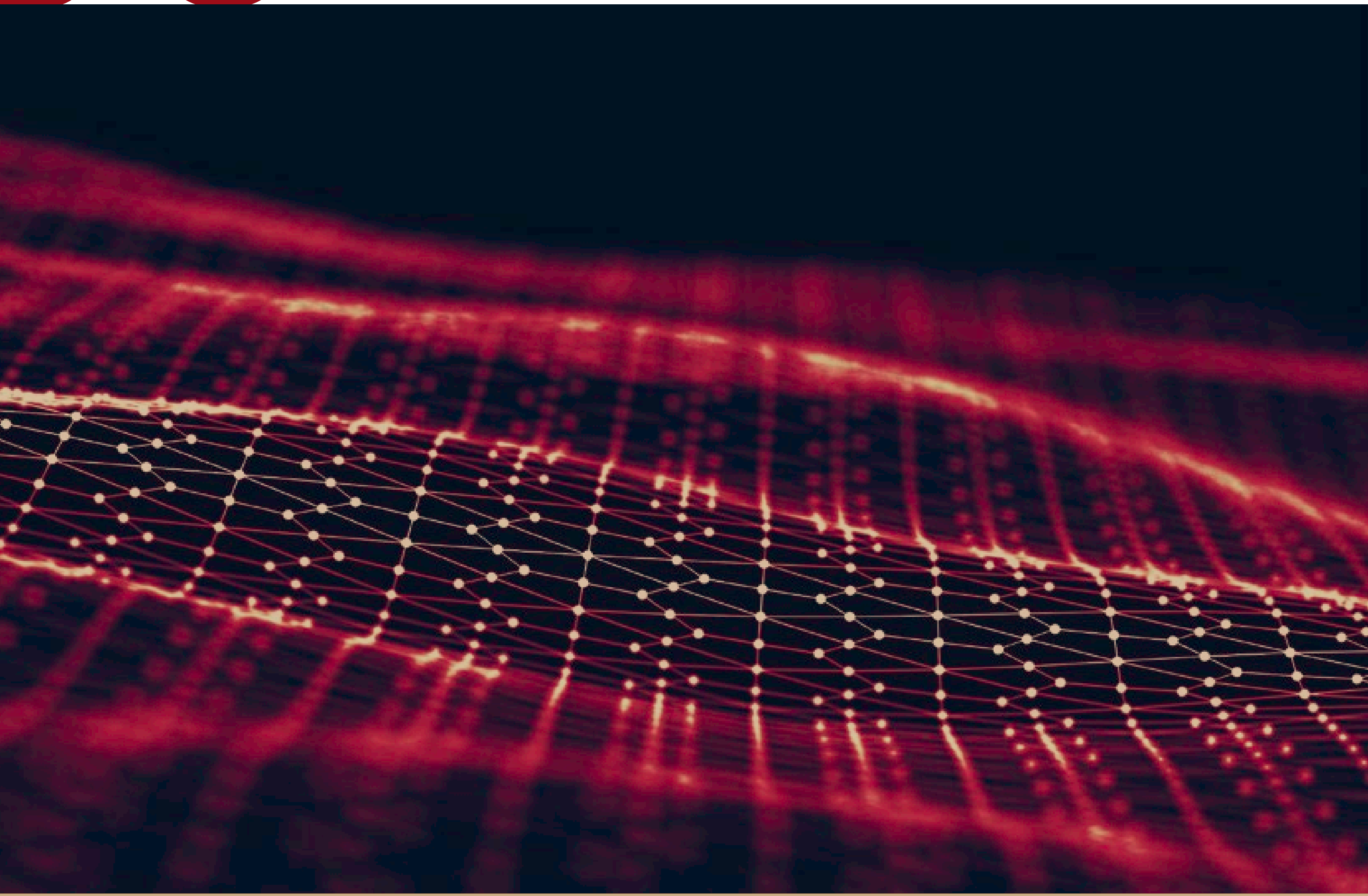

Science and Technology

BRAZIL AND THE NEW KNOWLEDGE ECONOMY

national projects | innovation | S&T policy | agricultural science | science and defence | aircraft manufacturing | electrical system | structural challenges | energy matrix | technology

HUMBOLDT-VIADRINA
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contents

For a civilizational revolution in Brazil

Carlos Siqueira
National President of the Brazilian Socialist Party.

The topic of science, technology and innovation has often been the focus of the Brazilian Socialist Party (PSB) for a long time. Party leaders have led this public policy as ministers of state who have sought to include it within the framework of the ideology of democratic socialism.

For the PSB, the concept and implementation of science, technology and innovation policies should be based on a national vision, the position of the country in the world and the ways through which progress should contribute to revolutionizing Brazilian society by overcoming the colonial mentality that stillhas the cleardomestic ramifications of inequality, prejudice and violence, as well as international ones, since part of our elite only sees Brazil's international participation within the limits of its own interests.

Thinking about the country requires the formulation of a strategic development project with a fifty-year horizon, not the next elections or the future government. This time horizon requires a broad consensus that reconciles the political world, economic elites and civil society around basic ideas that not only make sense but stimulate everyone as participants and beneficiaries in the success to be achieved.

It is essential to leavebehind the mentality of a colonized countryto seek a position in the world that takes us beyond the condition of exporter of commodities.

First of all, we need to revolutionize our industry by making technology-intensive, value-added production that manufactures and exports finished products, instead of concentrating on the intermediate stages of the production chain only to then import finished products at a higher price when we should have made them domestically.

It is imperative to devise strategies that will lead us to a knowledge economy. We must make every possible effort to overcome all limitations, to be producers of technology in all the relevant areas, such as robotics, biotechnology, systems and information, mobility and automation, among others.

We need to overcome the educational challenge – a gigantic task. We must win the fight against illiteracy, opening the doors of literate society for all Brazilians.

Regarding basic education, it is imperative to bring quality to the universal education that we currently approach. Children and young people must acquire the essential knowledge in language, humanities, and mathematics. To achieve this goal, we must be political – in the best sense of the term – in order to muster determination and not merely excuse the inaction from the failure we have had in the past. It is essential to look ahead, learn from the world, try solutions that have not yet occurred to anyone, and definitely take the long-look with proper planning, budget, and correctly formulated policies that are supported by a sufficient and efficient structure.

For university education, it is fundamental to increase the proportion of technical careers, as compared to those associated to the humanities. This necessity has nothing to do with giving value to one over the other, but with a need to rebalance the two types of educationin which emphasis on one has led to the detriment of technical careers. This is a key success factor in the production of technology, as the recent stories of India, China and other Eastern Asian countries have demonstrated.

Although essential, the aforementioned conditions are not enough to organize science, technology and information policy.

It is essential to engage teaching and research institutions on the one hand and companies on the other.

Investments for such policy should be incorporated by companies into their production routines and investment planning. Such consensus requires state interference, since research is traditionally carried out in Brazil by the public universities.

Many successful examples deserve special attention. Initially, it is worth mentioning the Brazilian Agricultural Research Corporation (Embrapa), which formed a broad set of technicians and carried out applied research in its all operational sectors, contributing decisively to the development of Brazilian agriculture, natural diversity and the protection of our biomes.

In the materials segment, there is a nucleus of excellence articulated by the Brazilian Navy, together with universities, which has investigated special alloys and new materials that have decisively contributed to dominating the uranium enrichment cycle.

The production of civilian and military aircraft is already consolidated, making Embraer one of the world's leading companies, especially in the design and production of small and medium-sized aircraft that are essential to the competitive market for domestic, regional and short-haul flights.

However, there is much to be done to reach very important steps in achieving our own sovereignty. The development of satellites and the Brazilian Space Program are examples of where lack of strategic vision has led to no investments in the sector. The overall scenario can be measured by the treatment received by Alcântara Cyclone Space, a binational company formed by Brazil and Ukraine, which had among its objectives the transfer of aerospace technology. After years of efforts and significant resources allocated to the project, it was simply abandoned, considered an "exotic idea", disregarding the relevance of mastering technologies that clearly affect Brazil's strategic economic interests, as well as impacting our defence policy.

The Brazilian hydropower system has reached great maturity, allowing us to conceive and execute complex engineering projects that give us a considerable edge on the energy front without exaggerated environmental impact, since we have only moderate dependence on fossil fuels to produce electricity.

However, we have not yet reached the clean energy matrix that is compatible with the country's potential. We have developed knowledge for the production of electric energy from biomass, sun and wind, which can be applied at different levels.

Despite so many possibilities – from dominating nuclear energy to benefitting from geography that could make the Brazilian Northeast a major producer of clean energy – there is still a lack of investments and appropriate policy, which significantly limits our growth.

Despite all the recent difficulties of the company, we cannot fail to consider Petrobras as a successful story. In addition to being one of the largest companies in the world, it has achieved technological leadership in exploring and drilling offshore, deep-water oil wells.

What do these examples, among others, teach us for the future of a national development project? Initially, it is essential to design a strategic vision for the future. We must make all the necessary efforts to the technological qualification of our industrial complex, organizing a sectorial policy adapted to this objective.

In the last decade, Brazil did not have an industrial policy that deserved to be called as such. Strategic priorities were not drawn, nor were investments in industry increased. The result of this "non-policy" can be seen in a strong deindustrialization of the country with severe impacts on levels of income, jobs and wealth – the trajectory of which only is not more catastrophic due to the informal jobs that have relieved the despair of those who could not find gainful employment.

Service activities are also increasing, but the quality of most enterprise and jobs created is poor.

Biotechnology is another major strategic frontier in science, technology and innovation, since it can greatly contribute to the use of Brazilian biomes, while strictly adhering to the requirements of environmental preservation. In this context, the Amazon is a specific reality, due to its potentialin biodiversity, pharmaceuticals and others. It also has an impact on national defence, since it is not easy to maintain such large territory without exploitation of any kind, especially to enhance its preservation.

Finally, it is necessary to develop a national electric-electronic industry to get rid of the status as permanent importers of goods of low technological complexity that are very important in the consumption of families – a situation that puts constant pressure on the balance of payments.

These concerns hereindiscussed are present in the articles that make up this issue of Politika magazine.

The PSB's history is built on the defence of a social agenda, one of development and national sovereignty. We cannot aim low or propose only what is conventional. We must not resign ourselves to that which concerns only a part of our elite, whose patriotism goes no further than the short space of its interests.

The PSB is a collective subject for a civilizational project aimed at achieving the highest results in technological development, in the context of a strategy for the social inclusion of each and every human being, until each and everyone can achieve full autonomy.

I wish all the affiliates, leaders, supporters and citizens take the best advantage of this read and in believing that we can build a different and better Brazil.

Ricardo Coutinho
President of the João Mangabeira Foundation.

The challenges of science in Brazil

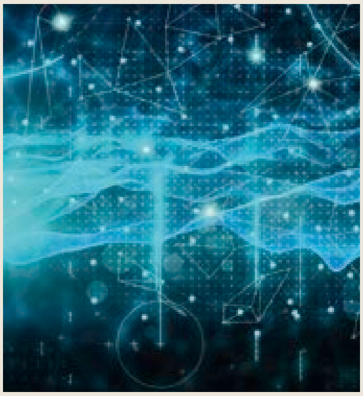
At the vanguard of the contemporary world economy are the agents creating new productive arrangements, new processes and new products. In the few domestic arenas, the few major companies that concentrate on the dynamics of innovation continuously capture and command positions precisely because they can recreate them. That is how they gain advantages in the international division of labour.

To support this process, peoples of the most developed societies are increasingly engaged in research, development, design, planning, education and other related activities. They progressively occupy jobs dedicated to knowledge and information, *lato sensu*, compared to those dedicated to manufacturing. Even without performing manual activity, this collective intelligence densifies the productive chains and multiplies the social productivity of labour.

Further to this point of view, Brazil is facing great deadlock. Whereas in the twentieth century we demonstrated a great capacity to learn the techniques of the Second Industrial Revolution, we did not create a productive system capable of competing for the leadership of innovation. This has relegated us to a peripheral position.

However, we are clearly not at ground-zero: We form the largest and most diverse scientific and technological community in Latin America, with more than 120,000 PhDs in activity; we have established important research centres in several areas; we have created economic enterprises of world-wide excellence. The Brazilian Socialist Party has already made great contributions to such activities.

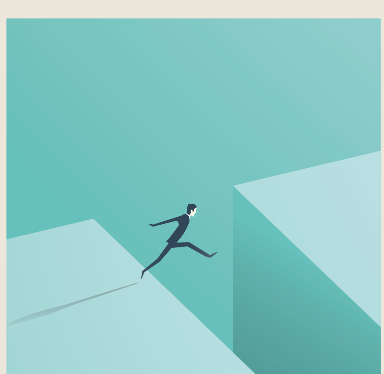
In order to deal with this complex reality – full of problems and possibilities – we divided the agenda of this issue of *Politika* on science and technology in Brazil into three blocks of articles:
(a) those dealing with general issues of science and technology policy, covering the path taken; (b) those demonstrating Brazilian success stories; (c) and those discussing current challenges for the future.



Aldo Rebelo and **Luis Antonio Paulino** present the issue of science and technology from the point-of-view of a national project, which can be used either for the domination or the emancipation of peoples. Since the dawn of modernity, nation-states are decisive, since only they are capable of assuming the risks associated with high, long-term investments and the uncertainties related to the maturation of important innovations. All major private technology companies – such as Apple, Facebook and Google – have depended heavily on public investment for their very existence. Due to the retraction of our State, Brazil has lost ground in the new world division of labour, whereas Asia has gained prominence.

João Alberto de Negri and **Eric Jardim Cavalcanti** discuss the challenges of innovation in Brazil. The connection between scientific activity and the creation of technology remains embryonic. Brazil already produces about 3% of scientific articles published in the world, but it only registers 0.1% of patents. A low percentage of Brazilian industries creates new products. Our investment in research and development grows at lower rates in relation to the advanced countries and at a slower pace than the world average. This poor level is also linked to the continuous decline in the share of industry in GDP and the frailty of our services sector with the highest technological intensity.

Sergio Machado Rezende highlights the progress we have made, especially in the first decade of the 21st century, but draws attention to the instability that still prevails in public policies. He highlights the huge recent setback in the federal science, technology and innovation system, due to the frequent substitution of ministers – on average one per year – each one with their own priorities, causing the discontinuity of many programs. The merger of the former Ministry of Science and Technology with Communications demoted the S&T system to a lower level in the federal government hierarchy, and cuts in the budgets of CNPq and Capes reduced the number of grants. There is the risk of a setback.



However, there are success stories. **Antonio Flavio Dias Avila** shows how the triumph of Embrapa relied significantly on heavy investments in human resource development. The company currently has almost 2,100 researchers with PhDs from the best academic centres in Brazil and abroad. Qualified personnel, solid strategic planning and modern management processes have made Embrapa the most important worldwide reference in tropical agriculture. The company's performance was decisive for Brazil to achieve a five-fold increase in grain production between 1975 and 2017 while merely doubling the area planted. This gain in productivity guarantees surpluses in the country's trade balance on one hand, while it supplies cheaper and better food to the domestic market on the other.

In the contemporary world, science and technology are essential activities for defence policies. In this issue of Politika, we highlight the contributions of the Navy and Air Force, who have worked closely with universities, research centres and companies. **Carlos Alberto Aragão de Carvalho Filho** and **Guilherme da Silva Sineiro**

show that our Navy performs intense research in state-of-the-art areas, such as new materials, special alloys and the electromagnetic spectrum – ushering Brazil into the exclusive group of countries that dominate the entire uranium enrichment cycle. The production of submarines within Brazilian facilities guarantees the absorption of modern shipbuilding technologies, with a high degree of domestic equipment and systems.

Thiago Caliari and **José Henrique de Sousa Damiani** tell the story of how the Air Force supported the transformation of the region of São José dos Campos, São Paulo into one of the world's great aerospace production clusters with the integrated action of governments, private companies and academic centres of excellence. It is a very competitive sector with both civil and military applications; it

demands highly qualified human resources; and it has great barriers-of-entry. It is a sector that requires decades to mature.

Roberto Pereira d'Araújo reveals the specificities of the Brazilian electrical system – unique among power networks in the world and thus the object of great misinformation. At one point in its history, starting in the 1960s, Brazil clearly understood the potential of its geography and generated new knowledge in the production and distribution of electricity. As a network, the transmission lines began to play an active role in the supply of energy, adding 20% extra load to the system. The idea of operating each plant separately does not make sense. However, since the 1990s there have been attempts to broaden a market that is essentially a cooperative system, resulting in mounting expenses, complexities and irrationalities – the cost of which has been transferred to the consumer. In this case, a major Brazilian technological achievement is threatened.

The third group of articles tells us about future challenges. **José Cassiolato** and **Helena Lastres** highlight an important point: the Brazilian agenda of science, technology and innovation cannot be separated from social issues and the potential of development areas: food, health, education, housing, solid waste treatment, access to drinking water and a sewage system, among other essential services also demand innovative solutions that require a lot of knowledge. Brazil has a heterogeneous productive structure, presents important regional inequalities and has traditional sectors with great

weight in the generation of jobs and income. Therefore, we need to forge our own path, considering specific social and territorial conditions, which brings us back to the need for a national project. In addition, the authors emphasize that science and technology policies cannot be expected to succeed in a macroeconomic environment which is hostile to development.

João Bosco de Almeida tells us about the possibility of one great potential of Brazil. In a world that deals with scarcity, we can consolidate a clean and abundant energy matrix, based on renewable resources, since we have biomass, rivers, wind and sun on a large scale – not to mention oil, natural gas and uranium. He concludes the article with a challenge: In the 1960s it was decided that the development of the Brazilian Northeast would be done with industrialization. Today, the government could guide its policies so that the Northeast could be the main supplier of energy to Brazil using renewable sources. It is a brilliant idea to develop the region that has the best winds, receives the highest insolation, has 3,000 kilometres of coastline for the construction of offshore wind farms, houses the largest reserves of uranium, produces a lot of biomass and has large areas suitable for the planting of energy forests.

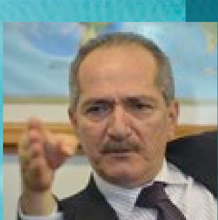
Finally, **Guido Bertucci**, from the United States, discusses the impact of the current Fourth Industrial Revolution, characterized by systemic changes and the interdependence of different technologies, with important digital, biological and physical innovations. Progress has been very fast in quantum computing, the internet of things, 3D printing, big data, data blockchains, machine learning and on-demand economics, which affects industries, businesses, professions and institutions. In the labour market, traditional professions tend to disappear, while others arise and are expanded. Government performance will need to change to keep up with so many transformations.

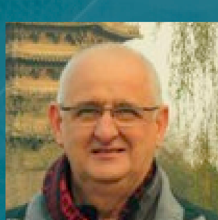
By delivering this sixth issue of *Politika*, with editions in Portuguese, Spanish and English, the João Mangabeira Foundation restates its commitment to the qualified debate of the great issues of Brazil and the world.

SCIENCE AND TECHNOLOGY IN BRAZIL:

challenges of the national project

The improvement of vessels gave Portugal the lead in maritime navigation. The steam engine set up the hegemony of England. Einstein's equation heralded the atomic age. Throughout history, science and technology have been instruments of domination and emancipation. Brazil's backwardness in these areas helps explain our process of de-industrialization, external deficits, and the loss of the skilled jobs that are precisely the best-paid ones. As Asia gains prominence, we are losing position in the new international division of labour – radically transforming the way we design, produce, and use things.





Aldo Rebelo[*] e Luís Antonio Paulino[**]

[*] Chief Secretary of the Civil Office of the government of the State of São Paulo during the administration period of Márcio França. He was Minister of the Secretariat for Political Coordination and Institutional Affairs (2003-2005), President of the Chamber of Deputies (2005-2006), Minister of Sports (2012-2014), Minister of Science, Technology and Innovation (2015) and Minister of Defence (2016).

[**] Full Professor at the São Paulo State University (Unesp) and director of the Confucius Institute at Unesp.

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Science and technology in Brazil: challenges of the national project

Introduction

The development of mankind is deeply linked to the efforts of scientific discoveries, technological achievements and innovations that improved people's material and spiritual living standards.

The management of fire as a primitive source of energy allowed man the first great upgrade in the precarious standard of living of the Palaeolithic period. The invention of the wheel changed the concepts of time and speed in the transportation of household equipment, objects for commercial purposes and military artefacts. The domestication of the horse on the steppes of Asia for riding and traction forever changed the locomotion for civil and military purposes. Cavalry modified the concept of warfare, as the horse extended military logistics as never before. The few horses brought by Hernán Cortéz were enough to establish the superiority of the Spanish invaders against the Aztec infantry in the region now occupied by Mexico.

Science, technology and innovation were combined to transform life and geopolitics in three emblematic situations: (a) the great navigations of the Portuguese and Spanish in the fifteenth and sixteenth centuries; (b) the steam engine, with the subsequent establishment of the industrial, commercial, military, diplomatic and cultural hegemony of England in the nineteenth century; (c) Einstein's formula ($E = mc^2$) was converted into the atomic bomb by the United States as an instrument of military domination in the twentieth century.

By bringing together the techniques and knowledge of the Chinese and the Arabs about navigation in the so-called Sagres School, Prince Henry assured Portugal the leadership in the race for the discovery of a trade route to Asia that would bypass the Turkish blockade, established after the domination of Constantinople.

Although of unknown origin, the Latin or triangular sail was introduced to the Mediterranean by the Arabs, allowing for navigation against the wind and helping Vasco da Gama in his adventures through uncharted waters. Due to its lightness and agility, the caravel was decisive to overcome transoceanic distances. The compass and the astrolabe completed the technological arsenal of the navigators – besides the onboard cannons, of course.

It was thus that the commercial influence of Portugal and Spain was spread across the world, together with the Catholic faith and their respective languages, spoken to this day by peoples of America, Africa and Asia.

The innovation promoted by the Portuguese led a small and sparsely populated country to a prominence that lasted for centuries in the geopolitics of the world. The epic *Os Lusíadas*, by Luís Vaz de Camões, raised the Portuguese literature to the level of the eternal classics by praising the glories and deeds of the Lusitanian navigators.

In the transition from the eighteenth to the nineteenth century, the Chinese economy ranked first in the world. But this scenario was soon changed by the adaptation of an ancient Greek invention of Heron of Alexandria: the steam engine.

> The degree of mastery of science, technology and innovation determines the position of each country in the international system. This is a matter of state. A national project requires a long-term vision, which cannot depend on the moods of financial markets.

The Englishman James Watt converted the Greek invention into a powerful device, which revolutionized the textile industry of England, which started leading industrial production and, thereafter, the economy of the planet. It was a prodigy achieved by the conversion of a scientific curiosity into invention, and of an invention into an instrument of a national development and a project of colonial domination.

Technology as an instrument of domination

In 1793, King George III sent Lord Macartney as ambassador to Emperor Qianlong to offer the wonders of English industry to Chinese consumers. After a period in the port of Rio de Janeiro for rest and supply, the great expedition arrived in China, where it was received with great pomp and pageantry. But Qianlong was not interested in the novelties. China produced fine fabrics in large quantities, so that the pieces of the British textile industry did not impress him. It would be later that the Chinese would come to know of another piece of equipment produced by the steam engine: the English gunboats that bombed and occupied the port of Canton. The Opium War forced China to open its market for drugs produced in the British colonies and the fabrics from factories of Manchester.

With its ports occupied by powerful European countries, China was subjected to a process of colonial domination. At the entrance of the English district of Shanghai one could read the inscription: "Dogs and Chineses not admitted". The humiliation was extreme, but the exploitation was even greater. The expression "Chinese deal" was born in that period, referring to transactions in which one side gained a disproportionate advantage.

It was not until 1998 that England returned Hong Kong to the Chinese. Macau was returned the following year, after an agreement between China and Portugal.

⋆ ⋆ ⋆

In the early twentieth century, the German physicist Albert Einstein revealed to the world an equation that summed up and synthesized the effort of scientists from many countries over many years of research: $E = mc^2$, whereby energy was equal to the mass multiplied by the speed of light squared. It was a revolution in science and a promise for the future of humanity: a small portion of matter could be converted into an enormous amount of energy. Einstein's discovery generated technologies of peaceful use: by centrifugation, for example, certain materials can produce fuel or derivatives used in the production of drugs for the treatment of many diseases. But the most important part of the equation came in the atomic bombs launched by the United States on the Japanese cities of Hiroshima and Nagasaki in 1945 at the closing of World War II. To this day, the Japanese archipelago hosts part of the US nuclear arsenal due to the surrender agreement signed after the conflict.

Research and production of derivatives of the nuclear industry are the only activities for which intellectual and industrial property is not recognized, which guarantees full freedom to the powerful countries to develop and multiply their arsenals.

Technology as an instrument of emancipation

In Brazil, the effort for innovation is confused with the very formation of the nation. In the sixteenth century, according to the historian Jorge Caldeira, "while European physicians manipulated something like 150 vegetal species, some populations worked with about 3,000 species. [...] 3/4 of all the medicinal drugs with vegetal origin currently used in the world derive from this native knowledge".[1]

Gilberto Freyre reports on the conflict in Recife in the eighteenth century between residents and Portuguese authorities, who forbade the activity of healers and *rezadeiras* (women who pray to cure diseases), who held native knowledge. With their plants, they dealt with tropical diseases unknown to European physicians with solid academic background.

Still in the sixteenth century, the Portuguese established in Brazil the first mills, the vanguard of industrial activity, producers of the most valuable commodity of that time: sugarcane. If we compare the production process of the first mill introduced by Mrs. Ana Pimentel in the São Vicente captaincy with the current second-generation ethanol industries, we cover a long and victorious trajectory of innovation in this important industrial activity in Brazil.

Dom João VI's license of 1809 – granting advantages to inventors and a period of monopoly over their inventions – is the first intellectual property law in Brazil and the fourth in the world, after similar laws in England, France and United States.

Bartolomeu de Gusmão, the Brazilian "flying priest", was the first man to make the airship, nicknamed "*passarola*", function in 1709, in front of the eyes of a surprised and amazed city of Lisbon. This tradition of Brazilians interested in overcoming the limits of gravity was followed by Augusto Severo and Santos Dumont in Paris in the late nineteenth and early twentieth centuries.

Before Santos Dumont, Augusto Severo had attempted the same achievement of the genius of the *14Bis*. The artefact of the pilot and engineer exploded in the air and crashed over the French capital. The street that witnessed the accident was named after the Brazilian inventor.

The memory of engineer, industrialist, inventor and politician Severo is not well-preserved, which is an injustice, since his effort is comparable to the saga of Santos Dumont in liberating man from the limits of gravity. In addition to a street in São Paulo, the old airport of Natal is named after him – far too little for such a great role model.

For a long time, the shortage of university and research centres restricted the scientific universe of the country to a group of researchers from military schools or from medical or law schools.

Arthur Ramos, Nise da Silveira, Anísio Teixeira, Josué de Castro, Pirajá da Silva, Rocha Lima, Samuel Pessoa, Alberto da Mota e Silva, Casimiro Montenegro, Carlos Chagas, Vital Brazil, Othon Pinheiro, among others, stood out as inventors and pioneers in social sciences, medicine, and in nuclear and space research as well.

Gilberto Freyre and Darcy Ribeiro in the Social Sciences; César Lattes, Mário Schenberg and José Leite Lopes in Physics: they are exceptions to the rule for academics dedicated to teaching and research in Brazil.

President Sarney created the Ministry of Science and Technology from the existing structures of the National Council for Scientific and Technological Development (CNPq) and the Studies and Projects Funding Institution (Finep). The first holder of the office was Renato Archer, a former disciple of Alberto da Mota e Silva, founder of CNPq. Both were Navy officers interested in science and research.

Today, Brazil has a sophisticated network of universities and institutes, federal and state ones – in this case, mainly in São Paulo – that are dedicated to scientific and technological development and innovation. This system has important financing instruments, structured in special funds or in specific laws, such as the *Fapesp* case in São Paulo.

A study released in 2014 by the Organization for Economic Co-operation and Development (OECD) showed that the world's resources for research, development and innovation had been cut in half. The crisis that hit the Brazilian economy also affected the federal government's budget for research, to the detriment of all the efforts in renewing the teams and the finance of equipment and projects.

When I was in charge of the Ministry of Science, Technology and Innovation, I prepared and presented a decree for President Dilma Rousseff, which included science and research as an area to benefit from the resources of

the Pre-Salt, along with education and health. At the time, I told the President it made no sense to dissasociate health and education, on one hand, from science and research on the other. I realized that there was not a single work linked to science, technology and innovation in the Growth Acceleration Program (*PAC*), and I said that it made no sense to seek development while neglecting science and research. I was able to get the works of the Sirius particle accelerator in Campinas and the Brazilian Multi-purpose Reactor in São Paulo into the *PAC*.

While still in the ministry, I defended the goal of reaching the 2% of GDP target for science and research. I pointed out the serious consequences of our deficiencies in science, research and innovation for the competitiveness of the economy and the quality of jobs generated in Brazil. The country's technological obsolescence explains the process of de-industrialization, growing current account deficits and the loss of qualified jobs.

Science, technology and innovation determined and continue to determine the position of the countries in the world. Being a protagonist or a simple dot in the world map depends on the scientific and technological capacity of the country, as much in economy as in defence. The quality of education and the capacity to innovate in industrial processes and national defence are the hallmark of the recent past, the present and the future in the dispute among nations.

The State behind science and innovation

In the 1980s, it had almost become common knowledge that the Japanese economy had become more competitive than the American one. People used to mock at the time about the expression "*my Japanese is better than yours*", in reference to the quality of the Japanese products, mainly electronic ones.

The dispute generated restlessness that crossed the frontiers of economy, invading geopolitics and the mass culture. Akio Morita unveiled Sony's achievements in his book "*Made in Japan"*, published in 1986. Shintaro Ishihara, an intellectual and former governor of Tokyo, widened animosity by releasing the text entitled *The Japan Who Can Say No*, a proclamation of threats to the United States and affirmation of the Japanese superiority. The English translation was released in 1991.

In the United States, the anti-Japanese wave was no smaller. In 1989, film maker Ridley Scott presented *Black Rain*, in which the actor Michael Douglas is an American policeman who goes to Japan to persecute the local mafia, *Yakuza*, and to execute its members. There could be no more explicit fable to reveal the state of mind of the United States towards the Asian country. In 1992, Michael Crichton, a bestselling author, published *Sun Rising*, a novel that denounces the alleged disloyalty of Japanese companies.

That was the atmosphere when Bill Clinton was elected President of the United States in 1992. He called on Laura Tyson, a Berkeley researcher, and set the challenge: how to meet the growing Japanese competitiveness and catch the breath of the American industry and technology?

Clinton received a critical but optimistic diagnosis. The United States was the biggest economy in the world, had the largest budget for science and research, had the best universities and institutes, and kept the best brains on the planet in their laboratories. The largest companies in the world were headquartered there.

In order to the country regain its leadership, the team of consultants recommended expanding research resources, increasing purchase from companies in problematic sectors and integrating the innovation system. When it was done, the idea that the Japanese economy would overtake the American one became a legend.

Mariana Mazzucato, a senior researcher in innovation economics at the Department of Political Science Research at the prestigious University of Sussex in England, has written the important book

Without the support of their respective nation-states, there would be none of the large private companies dominating the world economy. They did not happen alone.

The Entrepreneurial State, celebrated worldwide for defending the state's presence in the research and innovation effort. Supported by detailed research, Mazzucato proves that without government money there would be no big technology companies like those that dominate the world from the United States. Funded by the State, Apple, Facebook and Google resulted in applications and services that determine the American hegemony across the sector. Mazzucato's thesis states that only government can take the risks inherent to the high investments in science, research and innovation.

Americans continue to be challenged in the Eurasian space. Russia haunts by demonstrating the resumption of its military capacity, which has been largely victorious in the Syrian conflict. China shifts its scientific and technological effort to grant its economy a high technological standard and thus reaffirm its own trajectory towards the world leadership.

Technology: Modern King Janus

The impacts of the three industrial revolutions of the last 250 years were enormous. The first one radically transformed the world. New technologies introduced from the steam engine that mechanized spinning and weaving gave rise to new systems of production, transportation, exchange and distribution of products.

However, like King Janus, technology has two faces. The First Industrial Revolution contributed to enriching the world and raising the general standard of material life of the society, but also allowed the increase of the exploitation and expansion of colonialism. In the mid-eighteenth century, taking advantage of the technological, economic, and military superiority, England and the Allied Countries imposed the so-called "unequal treaties" or "wicked treaties" on countries as wide ranging as Brazil (Opening of the Ports in 1810), China (Treaty of Nanking in 1842) and Japan (Ansei Treaties in 1858).

Between 1870 and 1930, the domain of electricity allowed for the introduction of the new set of inventions and innovations – including the radio, the telephone, the television, electric lighting, home appliances and refrigeration – of the Second Industrial Revolution. Innovations in water treatment, sanitation and health allowed life expectancy to practically double in all countries. Chemical discoveries, such as synthesizing ammonia through the Haber-Bosch process, made it possible to produce nitrogen-based fertilizers in the preparation of the "green revolution" that occurred in the 1950s.

These technological advances widened the gap between rich and poor countries and were present at the outbreak of two world wars that cost tens of millions of lives due to the lethality of new weapons.

The development of digital technologies in the second half of the 20th century paved the way for a third wave of innovations in areas as diverse as information technologies, microelectronics, biotechnology, nanotechnology and robotics, among others. The reduction of transportation and transaction costs provided by the new information technologies, mainly the internet, promoted a new change in the global production system, leading to the creation of global value chains and the deepening of the process of the productive globalization.

This phenomenon generated a new international division of labour in which knowledge and technology-intensive activities are increasingly located in the rich countries, alongside the headquarters of large multinational corporations, as they are the most profitable and require qualified and well-paid manpower. Add to this the interest of these large companies in maintaining in their headquarters control over technology and industrial secrets. On the other hand, labour-intensive activities, especially the cheapest ones, as well as those intensive in the use of raw materials and energy, or more polluting, were moved to the developing countries.

This new international division of labour, made possible by the innovations resulting from the Third Industrial Revolution, has contradictory results. On one hand, it further deepened a division of labour that concentrates more value-added and more knowledge-intensive activities in the rich countries. On the other hand, enabling the integration of developing countries into global value chains has allowed their contribution to the global generation of wealth to exceed that of the rich countries for the first time.

The country that took the greatest advantage of this new situation was China, which became the second largest economy and the largest world exporter of manufactures. India has also benefited, occupying an important space in the area of information technologies.

Brazil and the new international division of labour

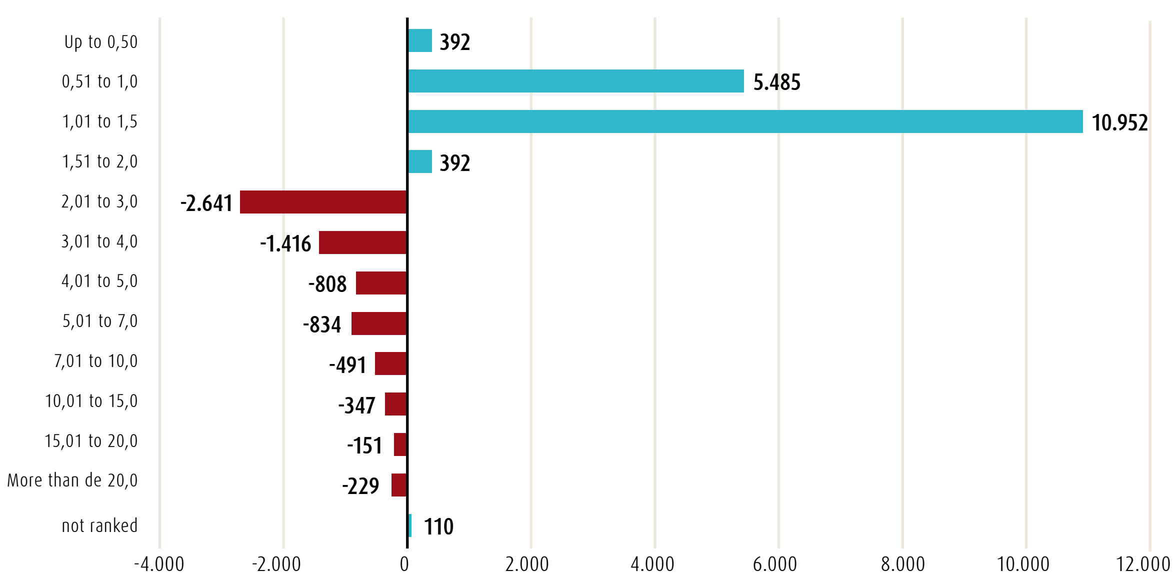
Brazil, unlike China and India, has experienced a premature process of deindustrialization, associated with a strong tendency to reprimarize the economy. This is reflected both in the quality of jobs generated and in the technological content of our exports.

According to Figure 1, compiled from data of the Ministry of Labour and Employment, the net generation of jobs in the country was 10.4 million of formal jobs between 2003 and 2017. However, the distribution of this balance of jobs by salary brings a worrying revelation: in the range of 0.5 to 2.0 minimum wages we had a positive balance of 17.2 million formal jobs, but there was a net loss of 6.9 million jobs remunerated above two minimum wages. The largest losses are concentrated in the range of 2 to 3 minimum wages (2.6 million jobs) and 3 to 4 minimum wages (1.4 million fewer jobs).

In Brazil there is a movement opposite to that of China. While the average cost of labour in the offshore industrial heartland of that country more than doubled compared to the industrial sector of the United States – from around 30% in 2000 to 64% in 2015 – Brazil has established a trend of generating increasingly underpaidjobs.

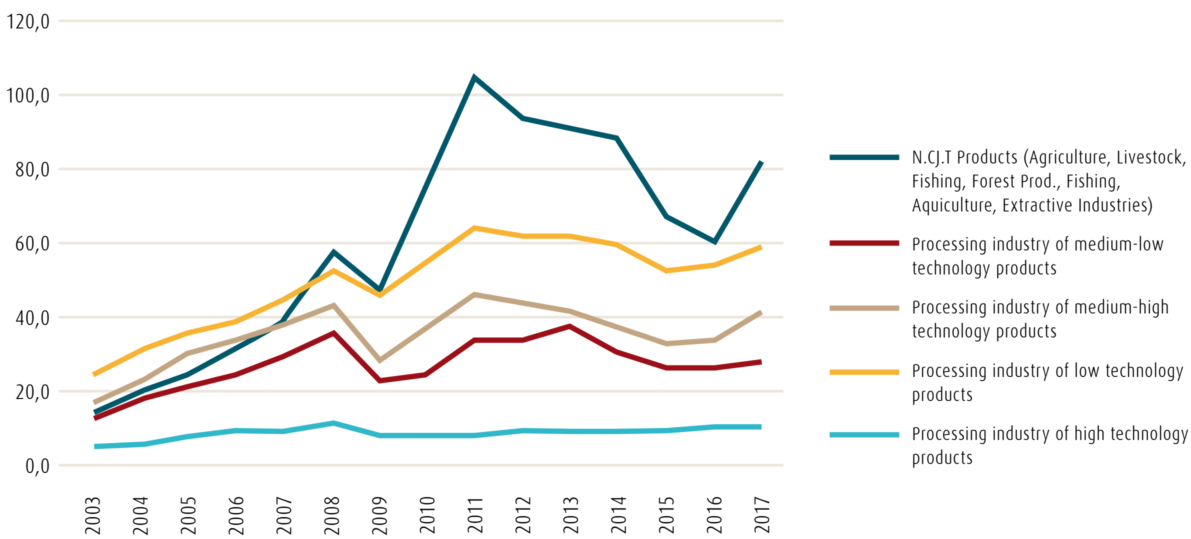
This phenomenon of technological impoverishment of Brazilian industrial production also appears when taking into account the evolution of our exports, split by technological content. As shown in Figure 2, between 2003 and 2017, the Brazilian export agenda was increasingly dominated by commodities, minerals and agricultural products, as well as products of the low-intensity technological transformation industry. The relative share of high technology products (aircraft, computer equipment, electronics and optical products, chemical and pharmaceutical products) is approximately at the same levels over the last sixteen years.

Figure 1 | Balance of formal work positions in Brazil by salary ranges in minimum wages (2003-2017) – in thousands



Source: Ministry of Labour and Employment, General Register of Employed and Unemployed (Caged). Authors' elaboration.

Figure 2 | Brazilian exports by technological intensity (2003-2017) – US$ billion



Source: Ministry of Industry, Foreign Trade and Services. Authors' elaboration.

The Fourth Industrial Revolution: new challenges for developing countries

The world is today witnessing the transition to what has become known as the Fourth Industrial Revolution. Advances in the areas of artificial intelligence and robotics, neuro-technologies, augmented virtual reality, new materials and energy technologies promise to radically transform how we produce and use things. The potential benefits and risks of these new technologies in all fields of human activity are enormous.

Compared with previous industrial revolutions, digital technologies carry a much greater risk that the winners of this new technological race can seize all markets and establish monopoly power. Google controls almost 90% of the global internet search and advertisement market, Facebook 77% of social network traffic, and Amazon nearly 75% of the e-book market.

The digital expansion of the Third Industrial Revolution allowed the expansion of global value chains and the integration of developing countries into the global production system. The current revolution can bring the inverse effect. Advances in robotics, artificial intelligence, new materials and 3D printing may render irrelevant the comparative advantages that have allowed many countries, including China, to become inserted in the global value chains.

More sophisticated robots, operating with artificial intelligence and increasingly cheaper, can eliminate the need to transfer certain stages of the industrial activity to countries with low-cost labour, as has happened in the last decades. We can see the shrinkage of the global value chains, leading to the exclusion of millions of workers and the precarious living conditions of hundreds of millions of people in the developed and developing countries. In the United States, for example, 94% of the new jobs created between 2005 and 2015 are "alternative forms of work," without social protections, labour rights or any type of significant control by workers.

Given this scenario, China has been taking a series of measures aimed at changing the basis of its current economic model. The transition of the country to a new path, based on technological innovations, is necessary to continue its development process. Having accelerated its growth in the last thirty years based on the use of mature technologies, imitation, scarce intellectual property rights, and even violation of intellectual property rights of foreigners in some cases, the question now is how to generate autochthonous innovations.

In 2006, the Chinese government adopted the strategic decision to make China an innovative country. In that year, the IV National Conference of Science and Technology established the following points: (a) technical progress would be the main driving force of economic and social development; (b) independent capacity for innovation would be the main link between economic restoration, change in the growth model and improvement of national competitiveness; (c) the construction of an innovative country would be the main strategic objective.

In 2015, the Chinese government launched a new industrial policy called "*Made in China 2025*", the main objective of which is to make the country independent in state-of-the-art technologies and less dependent on the import of components of high technological content (in 2014, China spent more with the import of semiconductors than with the purchase of petroleum). The plan is a combination of proposals to stimulate the country's technological goals. Taking German *Industrie 4.0* as a model, it is a roadmap to divert the industrial sector from labour-intensive activities and the manufacturing low-value products for which the country is known, to a model based on intelligent technology – which is especially usefully since labour costs are rising. Although the objective of the "Made in China 2025" project is to modernize the industry in general, R. Barbosa (2017) says that "the plan indicates ten priority sectors: new advanced information technology; robotics and automated machines; aerospace and aeronautical equipment; naval equipment and high-tech ships; modern rail transport equipment; vehicles and electrical equipment; power generation equipment; agricultural machinery; new materials, biopharmaceuticals and advanced medical products".

With this plan, China aims to produce high value-added parts and components, increasing the national content of technology products by 40 percent by 2020 and to 70 percent by 2025. Companies that benefit from such support are expected to achieve a participation of at least 80% in the domestic market in only eight years. The rise of China's high-tech industry has been boosted by the growth in R&D investments. According to the Battelle Memorial Institute, China is expected to overtake Europe in terms of R&D spending in 2018 and the United States in 2022.

Faced with these new challenges, Brazil has no alternative but to invest heavily in science and technology and in research and development, if we intend to play a role in the world in the twenty-first century. In fact, it is not an option, because the alternative is to become irrelevant. Brazil must invest heavily in science and technology and in research and development. ■

Note

1. Caldeira, 2017, p.23

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CHALLENGES FOR INNOVATION IN BRAZIL

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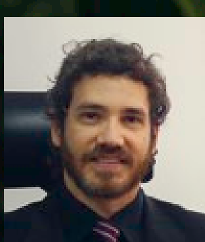

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The maturation time for science and technology initiatives is unpredictable, making the State a major player in the world. The more developed countries choose scientific areas and define critical technologies to be mastered, allocating resources to boost innovation in selected sectors. There can be no technological development without active participation of the public sector.

Introduction

Brazil will have to face great challenges in order to strengthen the competitiveness of its economy in the coming years. The technological frontier of the world does not stop moving. New manufacturing trends put pressure on those who produce goods and services. Advanced manufacturing, especially intelligent, aggregate manufacturing and robotic systems are the new frontier of knowledge and development.

Particularly in the business productive sector, Brazil cannot remain afar from this new frontier. The share of exports of manufactured goods fell 40% between 2002 and 2017, and the balance of trade of manufactured goods reached a very negative level, with highlight for imports of capital goods and durable goods. Two-thirds of capital goods are imported.

At the core of this debate is the education of human resources, particularly in the development of new areas in Physics, Engineering, Chemistry, Mathematics and other segments. Getting national production to the most advanced level – using information and communication technologies, intelligent sensors and machines in the industrial process – is a key issue for increasing income and generating better and more productive jobs.

There is potential demand, especially in critical technologies in the areas of energy, health, agriculture and defence. We need to anchor the advanced manufacturing initiatives in sectors where there are critical technologies to be incorporated in the Brazilian productive sectors.

Brazil needs to think of intelligent manufacturing from institutional structures that use the open laboratory concept to develop, demonstrate and scale technologies applied to business projects. It is also essential to develop autonomous robotic systems, focused on remote manufacturing and applied in industrial environments, precision agriculture and special equipment. There are many challenges and possibilities.

In the last decades, the world S&T matrix has become denser and more complex. There is an interconnection between S&T areas, change of scale and intensification of the scientific production in all technological domains. The uniqueness of the technological paradigm of this world matrix, when compared with previous paradigms, is the close relationship between the scientific knowledge base and the technological production. This close relationship between science and technology explains why the advancement of a nation's scientific knowledge largely determines its capacity for technological innovation.

Hence the current direct relationship between the capacity to generate wealth and S&T leadership. Countries considered leaders in S&T are also economic powers with high levels of productivity growth and, therefore, strong economic growth. They present increasingly complex matrices in science and technology.

Brazil is out of sync with the world matrix, concentrating efforts far from the cutting edge where the leading nations do not make great efforts. Therefore, Brazil has maintained its relative position in the technological race, neither moving forward nor backwards, while other large- and medium-sized emerging economies, such as China and Korea, have changed their S&T structure and have overtaken Brazil.

From the second half of the 2000's onwards, there is a global S&T standard focused on the technological areas that support a new way of manufacturing products, such as information technology, biotechnology and electronics. Brazil has a lagged agenda of research, little structured and out of the focus of the technological dispute. There is great difference among the paradigms of Brazilian S&T, global S&T and that of the technologically emerging countries.

Is it possible to change this situation? What conditions are necessary to do so? There is only one answer to that: yes, it is possible to change Brazil in one generation! This requires conciliation between the main economic agents of the public and private sectors, appropriation of solutions found by other countries and the demonstration of reasonable persistence.

The conciliation between the economic agents of the main public and private sectors will be the

The culture of innovation must be present in the professional training of students, in the scientific activity of researchers and in the internal environment of companies.

thorniest issue in the coming decades, mainly because of the high tax expenditures in the recent past and the traditional industrial policies that have been active for decades in Brazil.

There is a long divide between Brazil and more developed nations. Is it possible to observe the experiences of other economies and use appropriate tools to accelerate our arrival at the frontier of the developed world? The answer is yes, as long as we are able to associate relevant public and private economic agents with a robust science base and an exchange of information about successful experiences.

Such *ex-ante* coordination goes far beyond the idea that liberalization and openness of the economy would automatically produce technological convergence among nations. This is an old and misguided view. Productive development based on science, innovation and technology requires policy. No country has managed to approach the technological frontier without establishing close cooperation between the public and private sectors. Brazil has backtracked and made mistakes in its opening process. The existence of a competitive environment is fundamental for innovation, since protectionism and isolation keep the economy and companies in their comfort zones. At the same time, the presence of the State is essential because the uncertainty and risk of this type of investment need to be shared and mitigated to stimulate corporate involvement.

The dynamics, pace and timing of the S&T production are not always predictable. That is why the State is a major player throughout the world. It is not by chance that advanced countries choose scientific areas and define critical technologies to be mastered, thereby allocating public resources to boost innovation. There is no technological development without an active participation of the public sector.

There is no easy way to achieve a faster pattern of economic development. The objective of this article is to address the challenges in three aspects that are especially relevant for Brazil: professional education for innovation, science, and corporate innovation.

Professional education for innovation

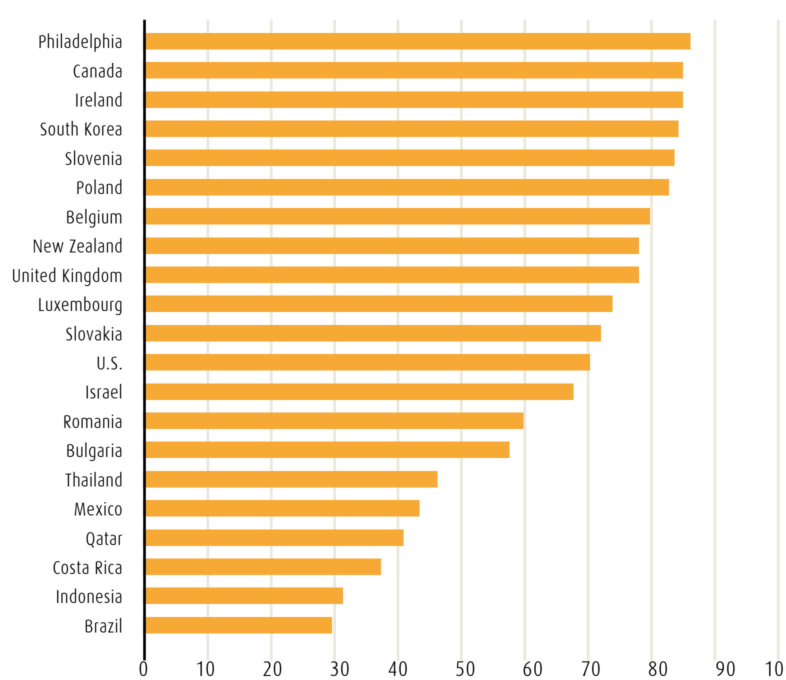
Brazil has dual characteristics in the education of its citizens and, consequently, in the formation of their professional and productive capacity. On the one hand, there has been progress in the process of universal basic education and also in increased access to college education. On the other hand, the quality of education has not kept up with the pace, remaining at the same or lower level, despite allocating sufficient financial resources.

The quality of the Brazilian basic education is low, especially in the publicsystem, responsible for more than 80% of the students,which profoundly impacts the human capital development conditions required to generate innovation and ensure sustainable growth in productivity. Indicators such as the International Student Assessment Program 2015 (PISA) have helped to shape this scenario: 91% of the evaluated countries present a mathematical performance superior to that of Brazil.

Brazil's performance in mathematics at PISA 2015 is scary: while only 30% of Brazilian students performed satisfactorily, more than 70% of the countries that participated in the examination enrolled at least 50% of students with satisfactory performance (Figure 1). This result is directly related to the decisions made by students when they finish the cycle of basic education. The decision to pursue careers in Human Sciences or other fields not related to mathematics and exact sciences is more common among Brazilian students, resulting in an insufficient stock of professionals in key areas for the processes of invention and innovation such as engineering, physics, chemistry and information technology, among others.

The poor performance of the country in examinations of basic educational knowledge is usually excused by insufficient resources.

Figure 1 | Percentage distribution of students with adequate performance in mathematics – PISA 2015



Source: Tafner (2018).

However, direct public spending on education has grown consistently over the years, as a proportion of the Gross Domestic Product (GDP), reaching a level equivalent to the international standard. Even so, Brazil's performance has been even lower than that of countries which invest less in education.

The evolution of expenditure has also been followed by improvements in the physical infrastructure of schools and in non-financial aspects, such as the reduction of overcrowding in the classrooms. However, contrary to expectations these advances were not reflected neither in the educational performance nor in the labour productivity.

Studies such as Hanushek (2013) indicate that the quality of education and the training of the workforce are the factors with greater impact on productivity and economic growth. Topel (1999), Glomm and Ravikumar (1992) and Benanou (1996), in turn, show that there is an overflow from education to productivity and that these effects are more associated to quality than to the average levels of education of the population.

More educated workers can transmit effects deriving from their school level to other workers, through stimuli resulting from observation and coexistence. However, this effect is limited by the degree of complexity of the productive process and the educational background of individuals. When the process involves a high degree of technological complexity, the overflow is only possible if the workforce has an educational level that can capture the stimuli in a relatively homogeneous way, which only occurs when it has a higher quality education.

The absorption of technology in Taiwan, Finland, Singapore, South Korea and some Baltic countries, until very recently, was only made possible due to the quality of education of its citizens. This achievement increased productivity rapidly and sustained complex productive processes by making important modifications in the institutions and in the business environment. Although not the only condition for development, skilled human capital is a critical factor in absorbing technology.

According to data from the National Household Sample Survey (*PNAD*) 2016, the schooling rate of the population from zero to seventeen-years-old has increased in the last ten years in almost all income quintiles. In a decade, average schooling went from 6.2 years to 8.7 years. However, we should not be deceived

by the evolution in the indicators, since the speed of this trajectory is still far from ideal. At this rate, satisfactory levels of schooling would only be achieved in about half a century. In addition, the indicators that measure age-grade adequacy and quality of education did not follow the positive trajectory. Brazilians have almost 30% less years of completed study than what is considered ideal for the age.

This diagnosis shows that there are obstacles in building a human capital base prepared for accelerated technological changes. Developing a productive profile focused on innovation also seems to be compromised by this situation that lacks basic competencies to boost the national innovation system. Every productive base is restrained by these constraints, which makes the Brazilian economy uncompetitive.

The college education system in Brazil has evolved significantly in the last few years, following the trend of all the countries of later development. There is a growing demand for qualified professionals and, consequently, a significant increase in the demand for college or technological education. However, Brazil has a late history of developing academic institutions and universal educational policies. Registration in undergraduate courses, for example, rose from 3 million to 8 million between 2001 and 2015, largely as a result of expanding private education, responsible for receiving 76% of the enrolled *INEP* data compiled by Schwartzman (2018).

Less than 1/4 of the students enrolled in higher education in Brazil are immersed in environments that stimulate innovation. The vast majority do not have the opportunity to take part in research groups.

Brazilian college education has little diversification. In universities, the colleges of Education, Law, Business and others in the Human Sciences field are predominant; whereas technology courses, engineering and others in the area of exact sciences or applied natural sciences are offered on a smaller scale – this is directly related to the nature of these institutions (their incorporation, the way they manage people and resources) and the demandsfrom students and the labour market.

In terms of the production of scientific research, universities and public college education institutes clearly differ from the private universities. Most basic and applied research is conducted by public institutions, which are also responsible for offering most postgraduate courses. Thus, there is a great discrepancy between the concentration of the number of registrations and the locus of conducting research and generating new knowledge for the country. Less than 1/4 of the students enrolled in college education are exposed to an atmosphere that stimulates novelty and innovation, as well as having the opportunity to take part in research groups or activities of scientific and technological development in the academic environment.

Contrary to the structure of courses offered in private universities, public universities concentrate education associated with Engineering, Science, Mathematics, Computing, Agriculture and Veterinary Medicine. This situation deeply restricts the stock of human capital that is indispensable for the processes of production and innovation.

Although unintentional, Brazilian society had always reinforced the typical careers of State, creating a culture interested in the public careers strongly associated with supervision and administrative processes. There is a tendency to stifle the private initiative, both by over-regulation and by the State's relegating responsibilities to the private sector.

When faced with greater potential for jobs, salary and stability in the public sector, the stock of human capital that could flow to private sector careers in technology and applied sciences – greater promoters of innovation and productive inventiveness – tends to prefer careers in the former. Although the area of engineering, production and construction studies showed an increase in their recent relative participation – to the detriment of the Human Sciences and Arts area – there was no substantial change in the distribution between the people occupied by area of study and the courses chosen by the college students in Brazil.

It is also important to draw attention specifically to the percentage of graduates in engineering careers and other technical-scientific ones. The careers that comprise this group cover fields 4 and 5 of the International Standard Classification of Education 1997 (ISCED 97). Figure 2 below gives an initial indication of the relevance of this information in the world.

Salerno et al. (2014) indicate a correlation of almost 70% between the variables of GDP per capita and participation of professionals involved in science and technology in the labour force. These authors also performed a statistical test that seeks to remove the influence of variables such as degree of development, security of the business environment and other characteristics peculiar to each country. They obtained significantly positive results for the relationship between per capita GDP growth and the proportion of professionals from engineering and scientific-technological careers in the total workforce of the country.

The association between the expansion of per capita income and the insertion of these professionals into the productive process is directly related to the capacity of the economy to grow in the long term, since these individuals hold the necessary knowledge to implement technological innovation, a preponderant factor for sustainable growth and productivity expansion. Brazil occupies a disadvantaged position in this ranking of countries, which indicates its inability to expand a more dynamic and innovative production. It also reveals that the country is unattractive to international investment in more noble productive activities that require the use of more skilled workforce. Poorly competitive in this aspect, Brazil tends to move away from the most sophisticated global value chains.

Mostly for scientific and technological careers, engineering, exact and earth sciences accounted for almost 25% of the total number of postgraduate students. When including the areas of agricultural, biological and health sciences, which stand out strongly in the productive and scientific scope of the country, these percentages reach 53.4% of the total postgraduate students.

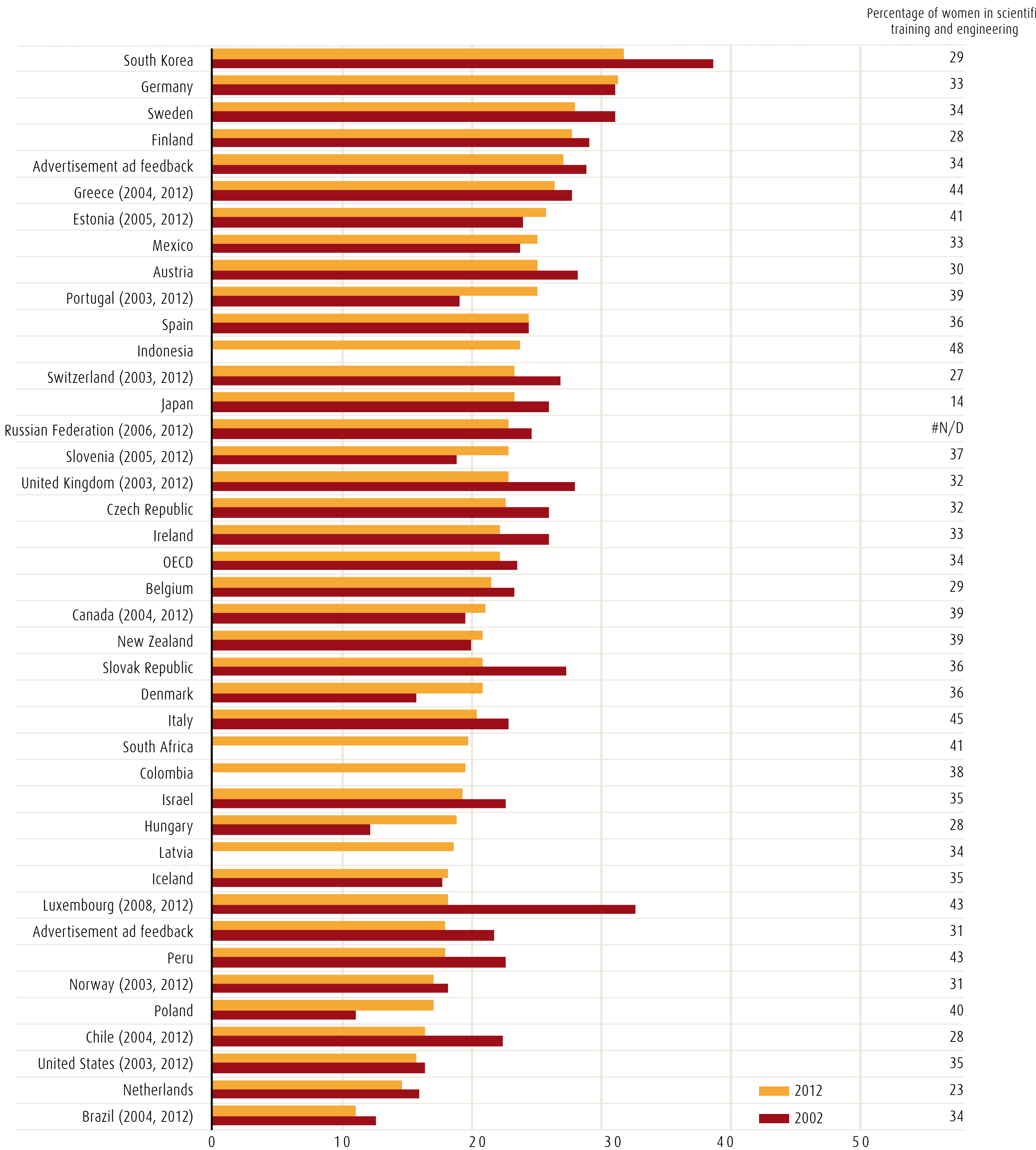
The expansion of the number of post-graduates also influences academic production. Publications of Brazilian authors in international magazines rose from 8,600 in 1996 to 62,000 in 2009. This number is 53% of the total for Latin America and 2.5% of all publications in international magazines of the world. On the other hand, the number of citations of articles written by Brazilians in the international literature fell from 29 to 8.3 between 2000 and 2010, suggesting a significant drop in the relevance of publications.

A relatively disperse and unfocused scientific production of Brazil was also identified. Data from 2016 of the Ministry of Science, Technology, Innovation and Communications (MCTIC) show that 200,000 researchers from 37,000 research groups in 531 institutions received resources to conduct research. A large part of these contributions paid salaries and scholarships. There isdifficulty in directing investments to laboratories focused on technological frontier activities and scarce resources directed to the development of new technologies for the productive sector. Several indicators reveal this situation. Particularly noteworthy is the small number of patents registered and the fact that most doctorates work in public universities, which demonstrates the weak link between scientific production and the Brazilian productive sector.

Science in Brazil

The production of knowledge depends on the existence of an extensive and modern hub of scientific and technological research, which is indispensable for economic and productive development. Most of the research and development (R&D) investments in the world come from universities and public institutions. In Brazil, the public sector accounted for almost half of the resources invested in R&D activities in 2014, the year in which the largest investments of the last decades were made in the amount of 1.27% of GDP. Despite the efforts to induce entrepreneurial investments,

Figure 2 | Percentage of graduates in Engineering and other technical-scientific careers in total graduates, 2002 and 2012



Source: OECD, available at: http://dx.doi.org/10.1787/888933273567. Accessedon: 05/10/2018 the proportion of the public sector in R&D investments has remained stable over the years.

A study conducted by De Negri and Squeff (2016) with data obtained in 2012 showed that 56% of the research infrastructure of the country was less than 20 years old and more than 70% of the outfits investigated had obtained significant resources for investments less than five years prior. The physical distribution of this infrastructureis aligned with the regions of the greatest economic dynamism in the country: 57% in the Southeast and 23% in the South. The physical area of these units in these two main economic regions totals 87% of the total physical area of the infrastructure involved in the survey.

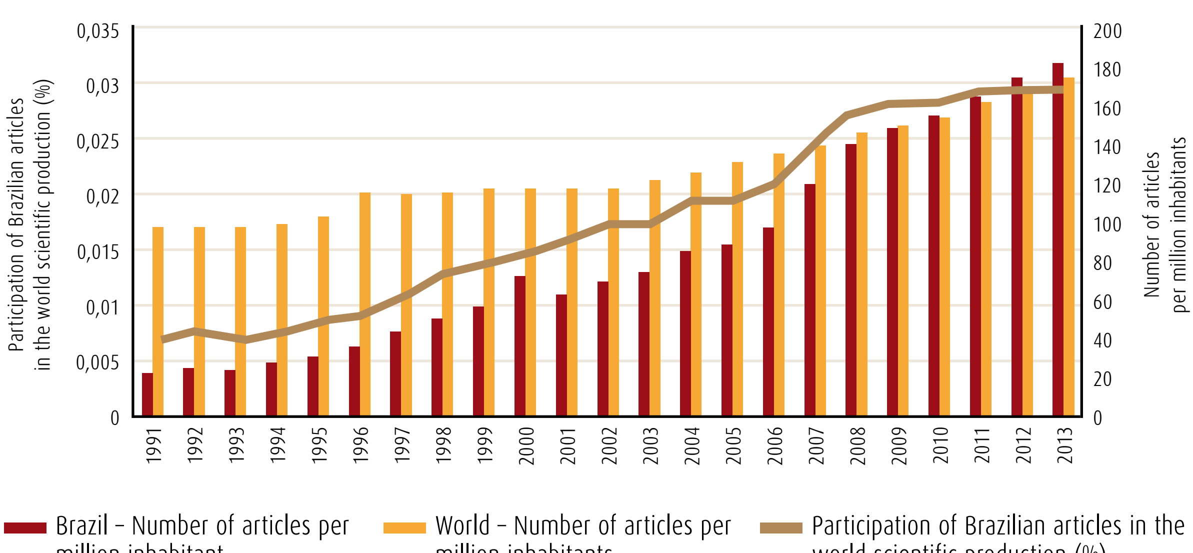
Infrastructure is concentrated in the areas of engineering and exact and earth sciences, which account for 57% of the laboratories and other research centres in the country. This data reflects the mismatch between the training of the scientific workforce and the infrastructure available for scientific and research activities. Only 25% of those enrolled and graduated in postgraduate studies come from these areas. The infrastructure for health sciences, in turn, represents only 6.87% of research infrastructures – despite being the most fertile area in the publication of scientific articles in Brazil.

In general, coordinators of the country's available infrastructure believe that the number of researchers and their education are still not adequate for the needs of the country. On average, there are only four researchers per laboratory. The number of external users served by such infrastructure is also low, predominately serving postgraduate students.

Despite the inadequacies and inefficiencies, the investments have produced increasing and consistent results when observing the metrics for evaluating scientific production. Brazilian scientific production changed between 1991 and 2013, moving from 0.7% of international scientific production to a percentage very close to 3%. As of 2010, the number of articles per million inhabitantsexceeded the world average, which confirms this observation (Figure 3).

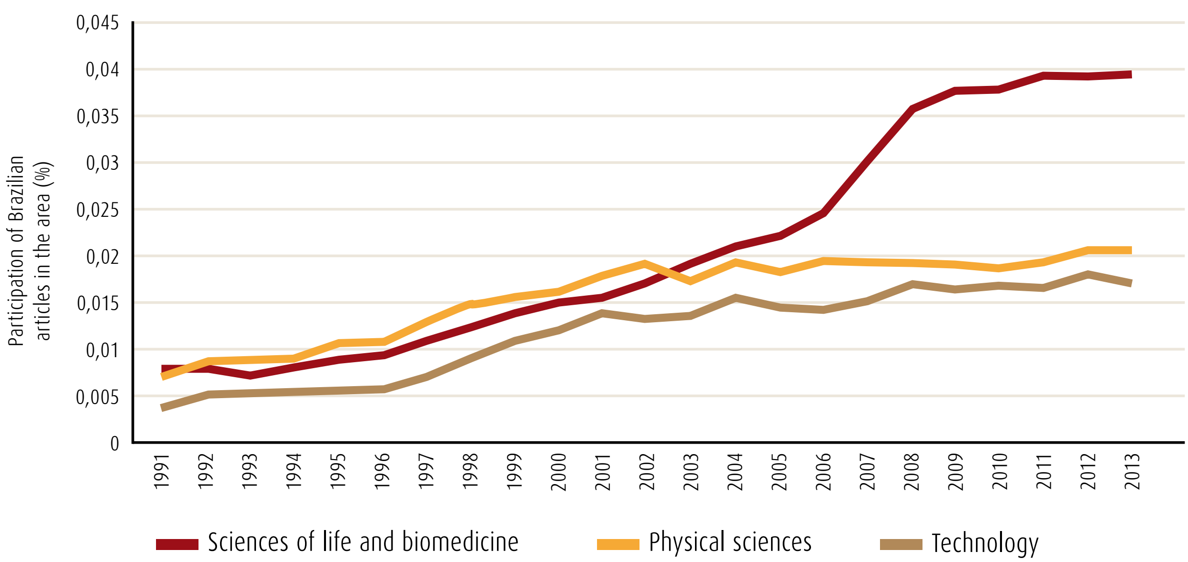
This trajectory comes from the increase in the number of publications in life sciences and biomedicine, physical sciences and technology during the 1990s. The number of articles in life sciences and biomedicine increased in the 2000s (Figure 4).

Figure 3 | Number of articles per million inhabitants (Brazil and world) and participation in world scientific production (Brazil) – 1991 to 2013



Source: Meyer (2016), ISI/Web of Science e World Development Indicators.

Figure 4 | Participation in world scientific production, by field of knowledge of ISI / Web of Science – Brazil (1991 to 2013)



Source: Meyer (2016), ISI / Web of Science and World Development Indicators.

Despite the quantitative leap in the number of Brazilian publications, their relevance seemed to go in the opposite direction. Considering the set of articles published, the citation ranking shows that the country moved from 15th place in 1991 to the 24th place in 2013. Restricting the evidence only to articles on life sciences and biomedicine – in which Brazil is a worldwide success story – the position in the citation ranking moved from 12th to 21st between 1991 and 2013.

Zago (2011) warns that it is necessary to change the management standards of scientific and technological production so that there are new quantitative and qualitative leaps. Optimizing infrastructure installed and fostering networks with international visibility via incentives for the development of new products and technological processes are decisive actions.

Despite the positive balance in infrastructure and scientific production and the ambiguous result in terms of quality of science, there is yet another hurdle that undermines the scientific and technological development of the country. There is a growing concern to expand the connections between scientific production and the productive sector, but the past few years have been seen a disjunction between these two players. On the one hand, the publication of Brazilian articles in international magazines indexed to the Institute for Scientific Information (ISI) reached 250 articles per million inhabitants, equivalent to almost 3% of the world total. On the other hand, the country's participation in the United States Patent and Trademark Office

Shrinking industry and the absence of a technology-intensive service sector discourage innovation.

(USPTO) patent concessions is only 0.1% of the world total. These figures show an undesirable mismatch between scientific production and technological production which needs to be solved.

In all these cases, public research institutions were apparently oriented to solve the problems relevant to a community of users and/or designed for certain sectors of activity from their very beginning (Mazzoleni and Nelson, 2005). The existence of clearly defined demands on the part of the productive sector seems to have contributed to these initiatives to surpass the "low degree of induction" of the policies of science, technology and innovation (ST&I), as identified by Guimarães (2002; 2006).

One of the great differentials of developed countries, such as the United States, is that public investment in R&D is aimed at solving concrete problems of society. In Brazil, the fosteringof science servesan end in itself. A good indicator for evaluating a country's public investments is to measure the resourcesallocatedto mission-oriented activities: when applied by specific ministries, such as Energy, Health and Defence, resources tend to sustain R&D activities related to specific problems. Resources allocated to horizontal ministries such as Education and Science and Technology (S&T), in turn, tend to foster more generic and diffuse results.

Most public R&D in Brazil is not results-oriented. Only 30% of the resources are invested in ministries with specific missions, a percentage that reaches 90% in the North American case (Figure 5).

Brazilian science can also promote innovations of greater technological content in the market, based on adjustments in the business environment of Brazil. In order to do so, it is important to change the agenda to build a friendlier atmosphere for companies and scientists by identifying the main rules and regulations that need improvement. It is necessary to consider legislation and to investigate the function of institutions, identifying changes needed to reduce bureaucracy, eliminate legal insecurity and ensure differentiated treatment for S&T activities. In areas such as life sciences, the Biodiversity Law must be monitored and frequently updated; in the same way, the implementation and regulation of the national S&T Law must be updated regularly.

Figure 5 | Distribution of federal public investment in R&D, Brazil and the United States – 2015

Brazilian Ministries	Percentage of total	North American departments and agencies	Percentage of total
MEC	35.8	Defesa (DoD)	47.9
MCTIC	32.9	Saúde (HHS)	21.9
Agriculture	17.5	Energia (DoE)	10.4
Health	10.1	NASA	8.3
Defence	1.3	Fundação Nacional de Ciências (NSF)	4.3
Communications	1.2	Agricultura (USDA)	1.8
Others	1.2	Outros	5.4

Source: De Negri; Rauen, Squeff (2017).

Technological innovation in companies

In the last twenty years, Brazil had a set of active industrial public policies. In the context of the Industrial, Technological and Foreign Trade Policy (PITCE) launched in 2003, the Innovation Law and the *Lei do Bem* (Law 11,196/05) were approved, representing the first steps to modernize the legal framework for Brazilian technological innovation. After the PITCE, two new industrial policies were issued: Productive Development Policy (PDP) in 2008 and the Greater Brazil Plan (PBM) in 2010. In addition, the Investment Support Plan (PSI) was created in 2009, and the main technological innovation initiative in the country's history was launched in 2013: the Inova Empresa Plan.

Even though the new instruments originated from the Innovation Law and the Lei do Bem and greater resources were allocated to the Sectorial Funds (created in 1998), the main agent of state investment in innovation was FINEP, which supported over a thousand companies between 1998 and 2012. BNDES also implemented actions and programs to support innovation.

Currently, the country has many instruments to promote technological innovation, the same as those offered by most developed countries: subsidized credit, tax incentives, subvention for companies, subsidies for research projects in universities and ICTs, among others. Figure 6 summarizes the main public interventions to stimulate technological innovation in the country.

These are the main sources of support for innovation and R&D in Brazil, regardless of their origin. However, they are initiatives only on the supply and/or production side. Many of the resources are strictly public funding; whereas others are not budgetary resources, coming from parafiscal funds or other sources. The table shows neither indirect, implicit or explicit subsidies – such as the interest rate equalization or the differential in the cost of fundraising – nor the fee charged by the final agent for operational programs from FINEP and BNDES.

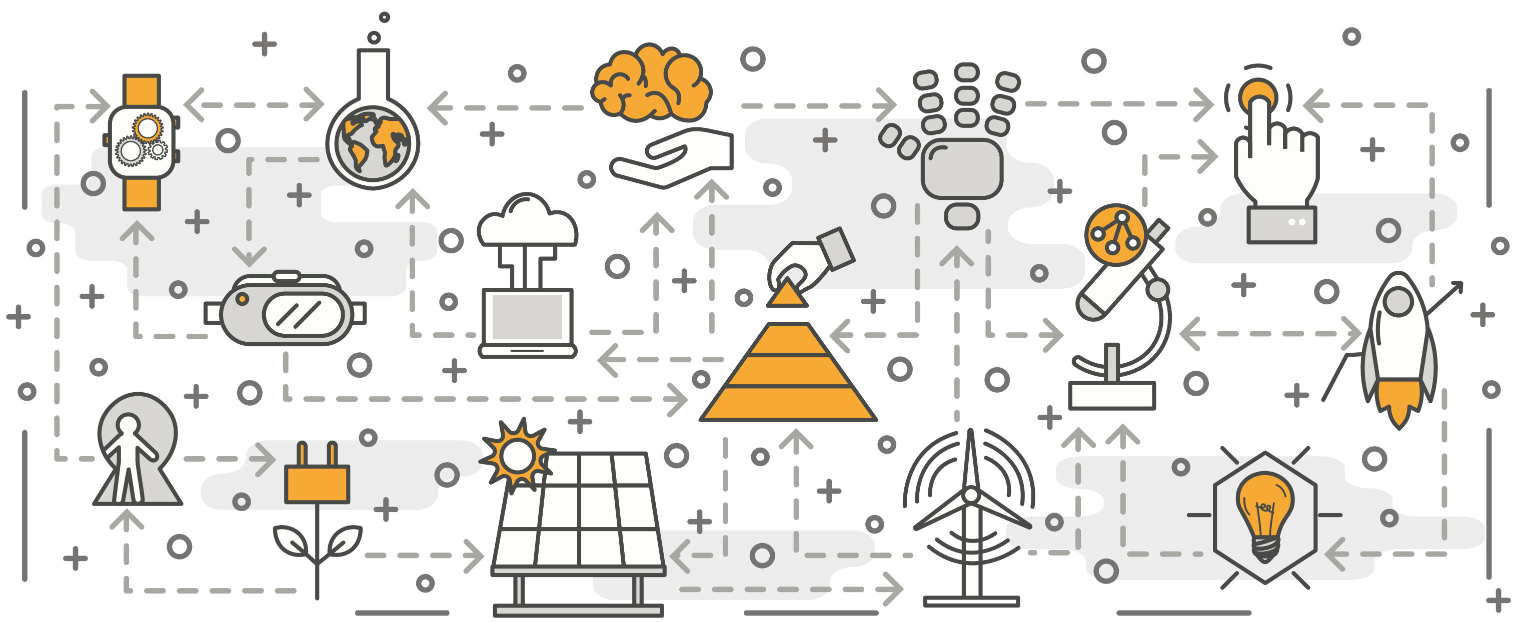
According to the statistics of the Research of Technological Innovation (PINTEC) of the Brazilian Institute of Geography and Statistics (IBGE) for the year 2014, companies that declared having received some public support to innovate grew from 19% to more than 40% between 2003 and 2014. This result already includes the first signs of the policies implemented by Inova Empresa. Nevertheless, most public support for corporate innovation was associated with financing the purchase of machinery and equipment. According to the innovation concept of the Oslo Manual, the acquisition of more modern and sophisticated production machinery, replacing outdated ones, constitutes process innovation. About 75% of companies that received public support to innovate have updated processes. Considering the public contributions focused specifically on innovation, in the strict sense, the number of beneficiaries has also increased, although in a much smaller proportion. In this case, according to PINTEC data, the number of companies in-

Figure 6 | Key federal policy or instruments to support technology and productive innovation in Brazil, 2015 (or latest available year)

Policies	Instruments	Amounts in *reais* in 2015
Tax exemption (1)	Law of Informatics (Laws n. 8,248/1991, n. 10,176/2001 and Law n. 11,077/04)	5.020.550.362
	Lei do Bem (Law n. 11.196 / 2005)	1.826.446.366
	Business expenses in R&D (Law n. 4,506 / 64 and Decree n. 756/69)	1.317.415.079
	RD&I in the automotive sector (Law n. 12,715 / 12 and Decree n. 7,819 / 12)	646.081.930
	Other exemptions (2)	818.355.571
Subsidized credit for innovation (disbursements)	Operated by FINEP	2.603.000.000
	Operated by BNDES (3)	4.501.000.000
Mandatory R&D of regulated sectors	P&D ANEEL	395.200,00 (4)
	P&D ANP	1.030.956.397

(1) Estimates made by the Federal Revenue Service of Brazil. Available at: https://idg.receita.fazenda.gov.br/dados/receitadata/renuncia-fiscal/demonstrativos-dos-gastos-tributarios/dgt-versao-para-republicacao_02-06-2016.pdf. Accessed on:23/11/2016. (2) Non-profit scientific organizations, machinery and equipment – CNPQ, PADIS, PATVD, scientific research – AFRMM and IT and TIC. (3) Excluding the amounts transferred to FINEP. (4) 2012 data extracted from CGEE (2015).

Source: De Negri; Rauen; Squeff (2017).



creased from 4.6% in 2003 to 8.6% in 2014.

The investment using company resources or from institutions that foster innovation and private productive technology is not very encouraging. Data show that business investment in R&D had decreased in PINTEC in 2011 when compared to PINTEC 2008 (the former covering the years following the international economic crisis that broke out in 2008), then showing a slight recovery in PINTEC 2014 compared to 2008. However, this information must be relativized, since the last edition of PINTEC was influenced by an outlier:an investment shock in the telecommunications sector for the expansion of the 4G network, due to the matches of the World Cup held in Brazil. If it were not for this event, estimates by De Negri, Zucoloto, Squeff and Rauen (2016) indicate that by 2014 investment in R&D would have been only 0.54% of GDP, which represents a drop from the 0.59% registered in 2011.

The persistence modest level of the R&D investment is partially justified by the continuing decline in industry's share of GDP and the lack of a burgeoning, technologically-intensive service sector (industry still accounts for around 80% of investment in R&D in the country). Another explanatory factor is the composition of the Brazilian export tariff, which over the years has shifted from a structure of greater technological intensity to one of lesser intensity.

Most of the innovations introduced by Brazilian businesses involve the commercialization of existing technologies, regardless of how new to the firm or to the domestic market. In the Brazilian market, there is little competition and goods are standardized. Therefore, innovations do not strongly explore the potentials of product differentiation to gain margins and market share. Companies seek to increase their margins through efforts to reduce costs through process innovation. In Brazil, process innovations are more frequent than product innovations.

Although about 20% of companies present product introduction and approximately 30% present process innovation, this type of innovation is predominantly for the firm, not necessarily representing anything new for the domestic or global market. When analysing the innovation numbers for the domestic market, this percentage drops to about 10% of all innovative companies, representing less than 5% of the industrial and service companies investigated by PINTEC.

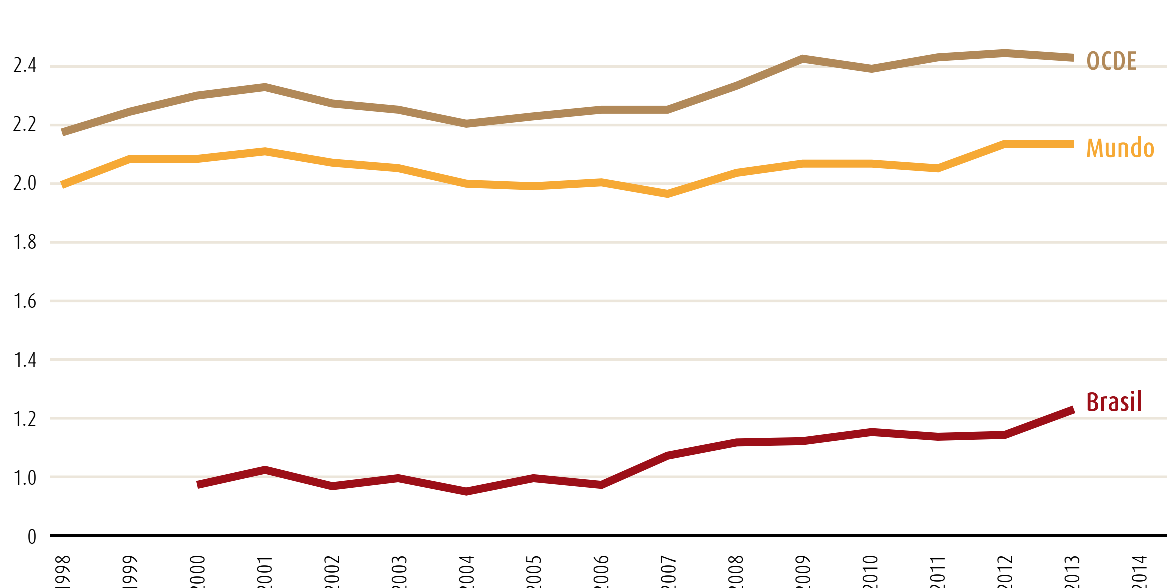
Even when considering corporate innovation, the introduction of new products and processes does not necessarily represent significant improvements. Following the guidelines of the Oslo Manual, the concept of innovation used by PINTEC is extensive, including the introduction of state-of-the-art machines and equipment into the production system. Thus, if a company modernizes its manufacturing plant, this effort is considered as process innovation, even if the production of the same goods is maintained, using the same type of inputs.

The innovation rates of the companies surveyed by PINTEC have not made great advances, ranging from 31% to 36% over the whole period under review – except when it reached the mark of almost 39% in 2008. In the 2006-2008 period that preceded the international crisis, economic activity in Brazil reached accelerated growth with an average rate of over 4% per year. However, the innovation rate decreased from 38.61% to 35.99% between the 2008 edition and the most recent edition of PINTEC. When considering only industry data, the extent of the decline was slightly lower: from 38.1% between 2006-2008 to 36.4% between 2012-2014.

Moreover, the Brazilian companies that invest the most in the intangibles of innovation and technological improvement do so at levels much lower than those of their counterparts in developed countries. Spending on intangible assets of Brazilian firms stood at around 4% between 2000 and 2008, much lower than that of countries like Japan, United Kingdom and United States, while similar to that of countries like Italy and Spain. The differential between Brazilian and North American firms' investment in intangible assets is in skills such as R&D, corporate governance and brand value. American firms spend up to ten times more on governance, three times as much on brand value and four times as much on R&D. According to Dutz *et al.* (2012), the differential with the economies of the Organization for Economic Cooperation and Development (OECD) is also significant for other types of non-technological innovation assets, particularly expenses on architectural and engineering design.

R&D investment grows in Brazil at lower rates than in advanced countries, and at a slower pace than the global average. However, it has been undergoing a process of expansion in recent years, the analysis of which requires some caution. Although the aggregate basis of expenditure has risen moderately,

Figura 7 | Research and developement investment as a percentage of GDP – Brazilcompared to OECD and world



Source: the World Bank. Available at: goo.gl/GeQHvh. Accessed on 05/10/2018.

the expansion of the index cannot be fully attributed to an acceleration of increased expenditures on innovation, since GDP has remained stagnant or declining.

In nominal values, R&D spending in Brazil has consistently increased. When compared to corporate revenues, these expenses have also shown significant expansion, increasing by 36.59% in the period 2000-2014 and rising from 0.75% to 1.03% in the net revenues of companies. However, this ratio is decreasing when considering the total expenditures on innovation. Expenditures on other activities of this type, not directly applied to R&D, fell from 3.09% to 1.46% of company revenues between 2000 and 2014. As a result, total expenditures on innovative activities (including internal and external R&D) in relation to the net revenue of companies fell from 3.84% to 2.49% in the fourteen years covered by PINTEC.

To gain long-term competitiveness, companies need to develop capacity to generate cutting-edge technological innovation. Adopting existing knowledge is not enough to produce consistent productivity gains. Both the incorporation of technology developed by others and the generation of in-house, state-of-the-art technology require a certain degree of human capital development, as well as infrastructure and accumulated learning – which greatly depends on the results from systematic processes of innovation and R&D activities.

Although Brazil has increased the level of spending on R&D activities in recent years, we are still far behind countries at the edge of technology. We have been overtaken by countries that were recently at lower or equivalent levels of development in the twentieth century. This increase in R&D spending was mainly due to the expansion of public expenditures, including resources for universities; public research and technology institutes; human capital education; and research infrastructure. As a result, the rate of researchers engaged in R&D has been growing, although apparently at a faster pace than that of the growth rate of expenditures on innovative activities.

In terms of private entrepreneurial investment in R&D, Brazil is far behind the average of the more developed countries. In this group, the proportion of private investment in total R&D spending was around 70% in 2014. Meanwhile, the same proportion was around 40% in Brazil, down from 44% in 2000. Therefore, a large part of the expansion in resources for R&D and innovation observed in Brazil has been due to the public investments of recent years.

Reflections on the innovation environment

The country has made increasing efforts in favour of innovation, but the results have not been proportional to the stimuli. Some strategies have been successful, especially in sectors such as agriculture – benefitting from strong incentives and public resources to develop technology – and in the strategic industries of aeronautics and renewable energy. Furthermore, there have been considerable improvements in training and development of human resources in S&T. Despite these experiences, the Brazilian private sector still does not fit properly into a systematic process of innovation and technological transformation. The R&D intensity and rate of technology adoptionof Brazilian companies are still far below the levels considered satisfactory in the contemporary global environment.

In recent years, public support for ST&I has grown. However, public investment in S&T in Brazil, especially in universities and other public entities, is up to eight times greater than the resources destined for innovation in private companies. Even so, little advantage has been taken from the technology developed by public entities – unlike South Korea, where the process from the outset was based on a system of long-term movement from public to private responsibility. The system of overlapping and interconnected agents and the private sector is fragile.

Accompanying these characteristics related of the ST&I system in the country, there are also exogenous aspects related to regulatory and management issues. Among all the impediments to the development of the national ST&I system, five deserve special attention: (i) regulation and business environment; (ii) public scientific research and collaboration with R&D in the private sector; (iii) effectiveness of innovation performed by firms; (iv) coordination of public policies; (v) evaluation and review of public policies. ■

Notes

1. NATIONAL INSTITUTE OF STUDIES AND EDUCATIONAL RESEARCH ANÍSIO TEIXEIRA. Synopsis Statistics of Basic Education 2016. Brasília: Inep, 2017. Available at: <http://portal.inep.gov.br/sinopses-estatisticas-da-educacao-basica>. Accessed on: 05/10/2018.
2. Brazil took the 67th position in the ranking with 72 countries participating in the PISA 2015 edition.
3. According to OECD Data, in 2013 Brazil spent 4.1% of GDP on education and its ranking in PISA 2015 in mathematics was 67th, while Mexico (3.9%), Poland (3.4%), Chile (3.1%), spent less than Brazil on education as a proportion of GDP and their positions in the PISA 2015 ranking for mathematics were 57th, 49th and 17th, respectively. Data available at: https://data.oecd.org/eduresource/public-spending-on-education.htm#indicator-chart Accessed on: 05/10/2018
4. Available at: http://www.mctic.gov.br/mctic/opencms/indicadores/recursos_aplicados/indicadores_consolidados/2_1_3.html. Accessed on: 01/10/2018.
5. Detailed data on the reality of technological innovation, R&D and other aspects of the Brazilian productive structure will be presented later.

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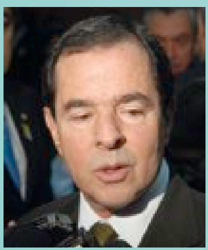
Advancements in the last decades and challenges for the future

In science, technology and innovation systems of developed nations, governments define strategy and policy; academia shapes human resources and generates knowledge; and firms conduct intensive technological innovation, creating new products and new processes. Throughout history, Brazil has been a late-comer, but already has a great deal of experiences in S,T& I policies: it has the largest and most qualified scientific and technological community in Latin America, with more than 120,000 researchers with doctorates. Brazil succeeds in important areas. We simply cannot go back.



Sergio Machado Rezende
Professor Emeritus of the Federal University of Pernambuco. PhD from the Massachusetts Institute of Technology. Secretary of Science, Technology and Environment of Pernambuco in 1995-1998, under the government of Miguel Arraes, and Minister of Science and Technology from 2005 to 2010, under the government of Luiz Inácio Lula da Silva.

Science and technology: engines of prosperity

In these times when the United States, backed by its military power and economic wealth, imposes its warlike and commercial whims on the world, Brazil has hardly any voice in the international scenario. The clear difference in the prosperity of the two nations leads us to the question: why have these two countries of comparable territorial size and natural resources, discovered and colonized by Europeans during the same period, reached the third millennium with such a discrepancy between their wealth and living conditions?

The reasons are many. One of the most important is the American ability to produce science and master sophisticated technologies – something that Americans possess and we do not. Although a considerable part of our society knows this, people do not quite understand just how significant this fact is. Politicians, entrepreneurs and economists in general think of technology as something that can be bought, believing our problem is fundamentally economic. There is a widespread perception that research and innovation are not within our reach, believing that with adequate public policies the country can develop economically and then buy the technology it wishes. It is a naive idea: technology is the application of knowledge and, thus, closely linked to science.

Americans have a formidable mastery of strategic technologies, having invested in education and developing science a long time ago. Around 1750, when science seemed restricted to Europe, Benjamin Franklin was already conducting experiments in electricity and contributing to the discovery of the law of conservation of electric charges. Franklin, the first American physicist, as well as a researcher, was a political activist. He founded a newspaper that preached libertarian ideas; he was a congressman for Philadelphia, playing an important role in the wording of the Declaration of Independence in 1776.

A hundred years later, the United States was already an independent and sovereign federative republic with a rapid process of industrialization. North American scientists pioneered experiments and disputed with Europeans in making great discoveries. In the second half of the nineteenth century, they contributed greatly to the development of electromagnetism, which resulted in the invention of the power generator and the electric engine, responsible for the use of electric energy in lighting and innumerable domestic and industrial applications, revolutionizing the habits of mankind.

They also invented the telegraph, the telephone and the radio, artefacts that revolutionized communications. Then came the first great entrepreneurs in technology: Alexander Graham Bell, inventor of the telephone, created a company to exploit it commercially, which then became AT&T. Thomas Edison invented the electric lamp, the charcoal microphone for telephones and the gramophone, among others, creating the Edison Electric Company, which later became General Electric (GE). Bell and Edison were not scientists, but they knew that without science and technological innovation their companies could not compete and win markets. That is why AT&T and GE created research centres and hired the first PhDs graduated from Harvard, MIT, Yale, etc.

To consolidate their technological dominance, however, more science was lacking. That was when the United States opened the door for scientists, such as Albert Einstein and many others who were fleeing the dangers of wars in Europe. Their work was essential in giving a major boost to the local science and technology system (S&T) and to create mass training programs for researchers through master's and doctoral programs.

After World War II, a number of North American companies created R&D centres, extended the hiring of researchers in the "exact sciences" and engineering fields, and expanding their capacity to innovate and launch new products in the market. At the same time, the federal government expanded the S&T policies and created several federal research institutes in strategic areas, along with various funding agencies. The most important ones were the National Science Foundation, the National Institutes of Health and agencies in the Department of Defence and the Department of Energy. These agencies have greatly expanded funding for research at universities, institutes and also for business, generally through defence, energy and health product development contracts. It was thus that United States dominated post-war S&T and attracted researchers from all over the world – mainly from Europe, Japan and Taiwan – to its universities, institutes and companies.

Defeated in the war, Germany and Japan began to prioritize S&T in the process of rebuilding their industries. And they were able to recover within a few years. Japan's progress contaminated other Asian countries. By the end of the 20th century, South Korea was already an industrial power. Figure 1 illustrates the correlation between economic development and scientific and technological development. The eight richest countries in the world, according to the gross domestic product (GDP) measured by the International Monetary Fund (IMF) in 2015, are the same eight countries with the highest number of S&T publications, according to the Scimago database.

It is incorrect to think that these countries invest in science because they are rich. The evidence is clear in pointing out that, as Oswaldo Cruz had said in 1900, that it is necessary to "meditate on whether only strong nations can do science or if it is the science that makes them strong." Or, as physicist Michio Kaku recently said: "Science is the engine of prosperity." The most notable recent example is that of China, which in 2002 had a GDP of about US$ 1 trillion, the seventh in the world. In the last three decades it has incorporated S&T into its development programs and established a state policy for the sector, expanding programs and resources, even among government changes. Today, it is the second richest country in the world and the second largest producer of science.

Figure 1 | Correlation between economic development and scientific development

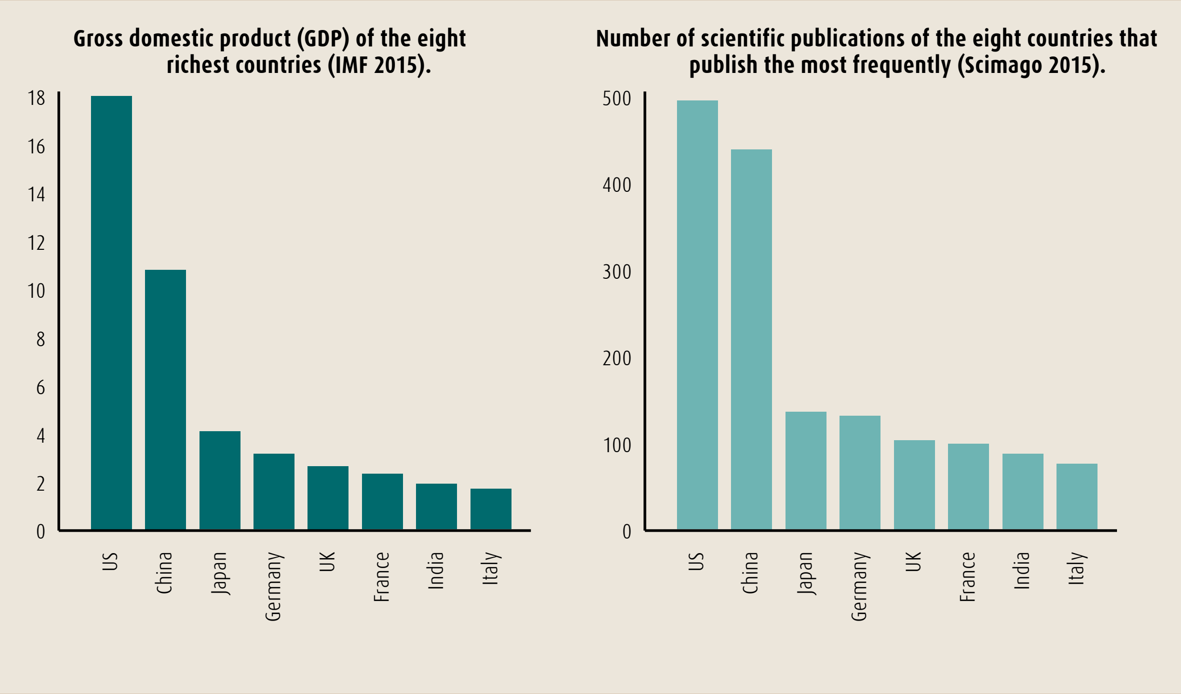
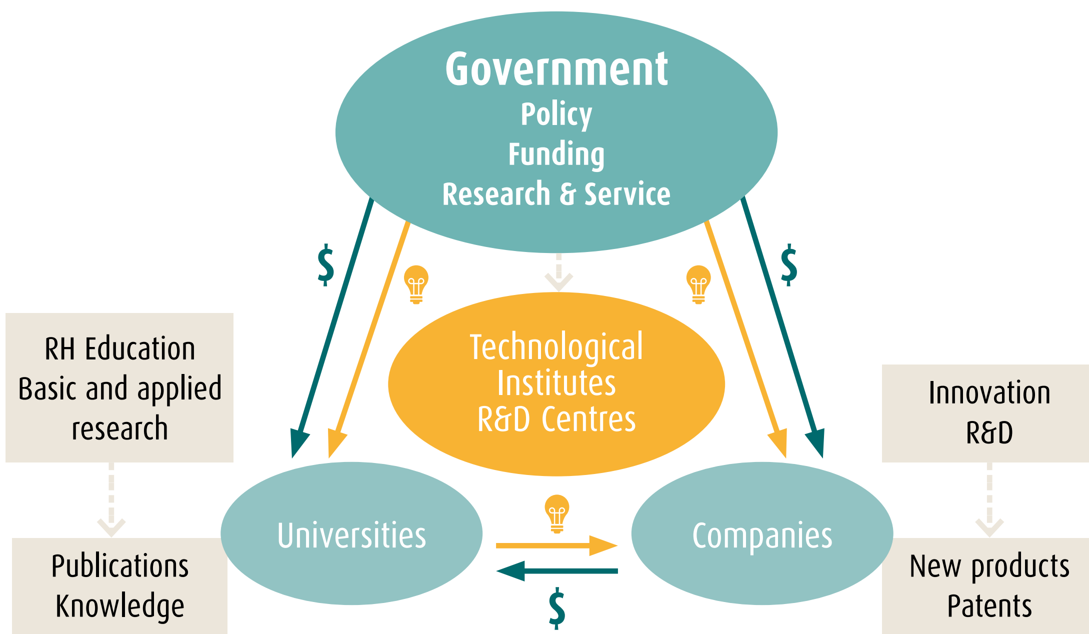


Figure 2 | Picture of a national system of science, technology and innovation (SNC, T&I).



What characterizes the eight countries of Figure 1, as well as many other industrialized countries, is a knowledge-based economy, for which it is essential to have a National Science, Technology and Innovation System (NSTIS). As it appears in Figure 2, a NST&I is basically formed by government, universities and companies. The role of government is crucial: it defines the policies and strategies of ST&I, articulating it together with other public policies – especially industrial policy. Universities have the essential role of forming human resources, generating knowledge to extend the frontiers of science, and producing new technologies. It is in companies that there is a more intensive effort for the technological innovation that generates new products, processes and services – or that incrementally improves existing ones – in order to make them competitive and win markets. In industrialized countries, governments account for at least 50% of R&D funding for universities and specialized centres, which are generally public.

Historical notes and late start of S&T in Brazil

The history of the education of politicians and businessmen in our country is very different from that of the United States. In Franklin's time, Brazil was governed by military governors, or viceroys, who took turns in power, protecting their personal interests and keeping the colony submissive. Our Portuguese colonizers did not allow the existence of typographies to print pamphlets, newspapers or books, essential vehicles for education and the diffusion of ideas. A hundred years later, there was still a slave-owning monarchy. The businessmen were sugarcane millers, coffee barons and cocoa farmers who dominated politics, protecting the interests of the elite and working in line with the holders of the international capital. Our independence was not conquered, but consented out of convenience by the rulers. Always restrained by external interests, Brazil has thereby developed with social injustice and without company production based on education, science and technology. We became specialists in producing simple products and exporting raw materials. Until the twentieth century, we had neither universities nor a broad system of basic education or national industries.

The first courses of Law and Medicine were only created after the arrival of the Portuguese royal family in Brazil in 1808. However, it was only 298 years after the founding of Harvard University that our first true university – the University of São Paulo – was founded in 1934. Until the 1960s, only a very small portion of the population had access to college education. With rare exceptions, college and school teachers pursued professional activities in other areas. Among other reasons, nor were they researchers, because there was no full-times job at universities. There were no postgraduate programs; neither were there any engineers or specialists in basic industry sectors. Our industrial park was incipient. There was no culture of innovation in the companies.

The foundations for changing this scenario were introduced in 1951 with the creation of the National Research Council (*CNPq*) and the Coordination for the Improvement of College Education Personnel (*Capes*), which began to grant scholarships for postgraduate education abroad and to support scientific activities in the small research groups that were being created. The performance of CNPq and Capes was fundamental to change the S&T scenario in Brazil, which in the last decades had four periods:

1. Construction and expansion of the National Science, Technology and Innovation System (NSTIS), 1960-1994;
2. Crisis and transition to a new financing system, 1995-2003;
3. Implementation of a more consistent federal S&T policy, 2003-2013;
4. Recent setbacks in the federal ST&I system.

The construction of financing mechanisms in the period 1960-1994

The construction of the National Science and Technology System in Brazil took place during the 1960s and 1980s. At that time, CNPq and the *Finaciadora de Estudos e Projetos* (*Finep*) – the Brazilian Innovation Agency – created in 1967 and manager of the National Fund for Scientific Development and Technological Development (*FNDCT*) since 1971, implemented many forms of financial support that became well-known in the scientific and technological community.

The greatest challenge for the development of science and technology in Brazil remains the lack of policy from the State. Governments change and, with them, priorities change – threatening the continuity of even the most successful programs.

According to the terms of its grant program, the CNPq conceded scholarships individually requested by candidates in the form of spontaneous demand, with deadlines established in an annual calendar that varied little in those decades. The main types of grants were: scientific initiation for undergraduate students; masters and doctorate, for postgraduate students; and research, for researchers from universities and research institutions (as an addition to salaries). The aid mainly involved the development of projects, the holding of events (congresses, conferences) and trips abroad, both for educational programs and internships, as well as for participation in events.

Finep provided non-refundable funding to research centres and academic institutes or departments by establishing covenants with a usual duration of two years, signed with host institutions or foundations representing them. Such institutional support, as it was known, provided funds for remodelling and refurbishment, acquisition of equipment, permanent and consumable materials, and other costs of research activities, including the payment of personnel. There was no fixed timetable: the candidate institution could submit a letter of consultation at any time; once approved, it enabled formalising the financing proposal. This type of institutional financial support provided the creation or consolidation of hundreds of research and graduate units during the 1970s and 1980s.

Finep's programs included institutions which acted in all areas of knowledge. But those most benefited by the resources of the FNDCT were the traditional areas, such as physical and mathematical sciences, biological sciences and engineering. In addition, institutional financial contributions were channelled to the Coordination of Graduate Programs in Engineering of the Federal University of Rio de Janeiro (Coppe/UFRJ) and to the Scientific Technical Center of the Pontifical Catholic University of Rio de Janeiro (CTC/PUC-RJ) for more than two decades. Since it was created, Finep has also financed engineering, development and innovation projects in companies through credit operations, with interest rates, grace periods and amortization periods that were very favourable if compared to the market conditions (loans from commercial banks).

Meanwhile, Capes devoted most of its effort to support postgraduate programs, mainly by granting masters and doctoral scholarships, and developed a competent system of accreditation and evaluation of postgraduate courses.

During the 1970s, the federal government developed two Basic Scientific and Technological Development Plans (*PBDCTs*), which guided the S&T policy for the following three years. In addition to offering budgets for the sector in subsequent years, PBDCTs also defined the programs for scientific and technological development and education of human resources for research, priority sectoral programs and strategies for their implementation. However, regarding S&T for industrial development, the plans were vague, similar to letters of intent, with little connection to the industrial policy in force.

When it was created in 1985, the Ministry of Science and Technology (*MCT*) absorbed Finep, CNPq and its research units into its structure. MCT was able to partially regain FNDCT's resources, which had been greatly reduced compared to the higher levels of the 1970s. The first MCT management achieved other important advances, such as the increase in the number of postgraduate scholarships at CNPq and the implementation of the Human Resources Training Program for Strategic Areas (*RHAE*). With a greater volume of resources, CNPq started granting postgraduate scholarships and RHAE scholarships in an institutional manner, approving quotas for accredited institutions in charge of selecting candidates. Later, in the 1990s, also scholarships for scientific initiation began to be partly distributed by quotas, in the Institutional Scholarship Program of Scientific Initiation (Pibic).

Difficulties in the full recovery of FNDCT budgets led the MCT to create a new financing instrument, the Scientific and Technological Development Support Program (*PADCT*), which ran from 1985 to 1998, using World Bank (IBRD) lending resources and counterparts of the National Treasury. The PADCT introduced three new features in the funding system of the MCT agencies:

1. Prioritization of areas. Only a few areas of knowledge were eligible for funding: chemistry and chemical engineering, biotechnology, geosciences, new materials, instrumentation, science education, S&T management and information, maintenance, special consumption materials;
2. Selection by public notices. The projects to be financed were selected through public call notices, prepared by the technical committees of each area and published at any time, with no fixed calendar;
3. Multiple agencies. The program was managed by an executive secretariat linked to MCT, under the guidance of a coordination committee, and was executed by three agencies, Finep and CNPq (linked to MCT itself) and Capes (linked to the Ministry of Education). The existence of PADCT led to remarkable advances in some areas, notably chemistry and biotechnology.

The late 1980s and early 1990s were characterized by great instability in the federal government's S&T management framework. MCT was extinguished and recreated more than once. Despite this and the irregularity of resources for scholarships and fostering initiatives, the financing instruments of Finep and CNPq were kept in their essence.

In 1995, under a new federal administration, MCT had an apparently consolidated set of financing instruments for the national S&T system. CNPq provided mainly scientific initiation, masters, doctorate, postdoctoral, research and RHAE scholarships, as well as grants for research, events and technical-scientific trips. The number of scholarships and stimulus budgets grew, although modestly, for several years, and the application schedule was well established. Finep maintained institutional funding programs with FNDCT resources, while PADCT funded research projects in the strategic areas established by MCT, selected through public calls.

Crisis and transition to a new policy of ST&I in the period 1995-2002

The scenario was substantially changed in the following years. At CNPq, the number of scholarships began to decline annually from 1995 onwards, while the research aid program was interrupted in 1997. In the same year, Finep terminated the institutional agreements in force, due to the drastic reduction of the FNDCT resources. In 1999, the PADCT, which was already in its third version, was deactivated, despite an open balance of credit with the resources of the World Bank.

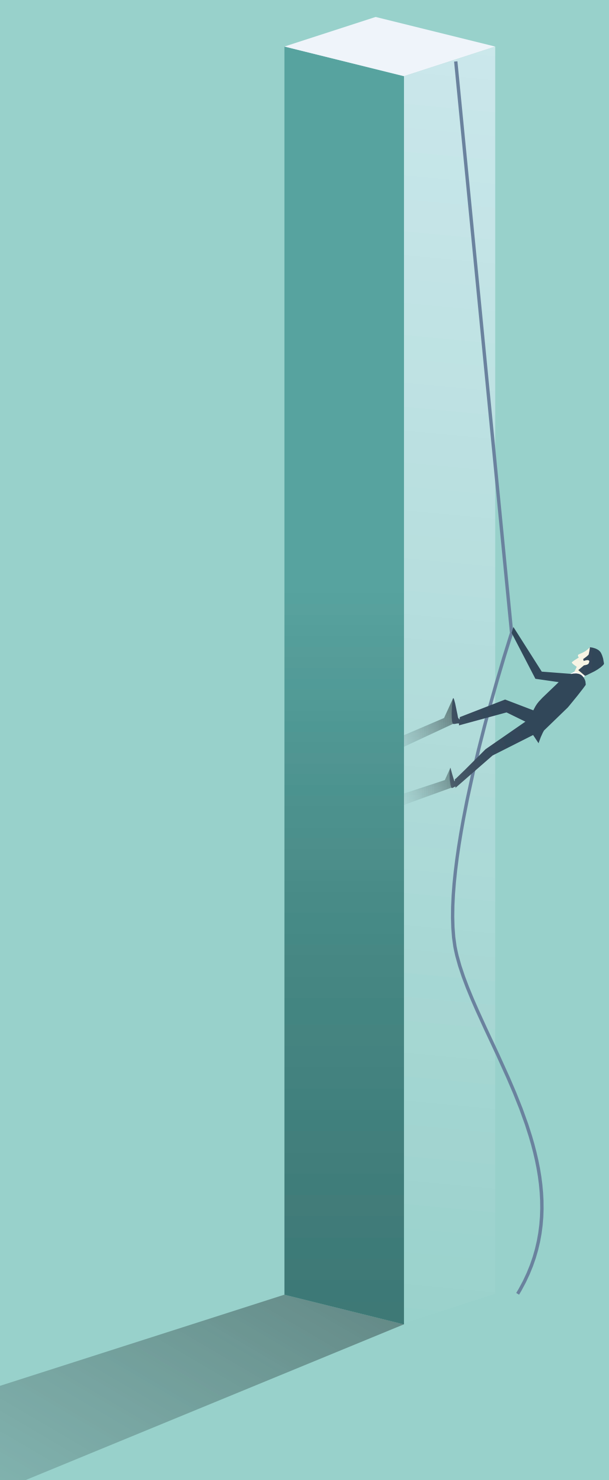
The discontinuity of Finep's institutional support programs was caused by the so-called "depletion" of the FNDCT. This did not cause major reactions in the scientific community, basically for three reasons:

1. With the significant growth of the S&T system and the limitation of resources for institutional support, most institutions were not included in Finep's programs;
2. The institutional contributions, mainly in the large institutions, included less qualified research groups, which benefited from participation in institutional projects along with more qualified and more prestigious groups;
3. During the 1980s and 1990s, other sources of federal and state resources were created to meet the basic maintenance needs of postgraduate programs and research groups. This occurred in a remarkable way in São Paulo, which concentrated around 50% of the country's researchers. The Foundation for Research Support of the State of São Paulo (Fapesp) had significant resources to foster research.

The reduction of FNDCT resources and research support at CNPq, as well as the discontinuation of PADCT microeconomic policy decisions led to a great discontinuity in federal S&T policy. This was due to the growing economic difficulties and the low importance attributed to the S&T sector by the main federal authorities of the economic area. Another factor of influence was the lack of more concrete evidence of the results of science and technology to increase the country's wealth and development. This last reason was due to the lack of investment from the business sector in R&D activities, the absence of industrial policies that could favour a culture of innovation in the companies, as well as the distance of the academic community from the productive sector.

The period 1995-2002 may be characterized as a transition period: on one hand, economic contingencies led MCT to discontinue traditional financing programs; on the other hand, the ministry laid the groundwork for the process of reconstruction of the S&T policy. This required the creation of new financing modalities and formats, and especially new mechanisms to ensure more stable sources of resources for the sector.

The modality of financial support for research projects spontaneously submitted to CNPq by group leaders, in an annual calendar, was replaced by three programs, implemented during the period of 1996-2000. The first one was the Nucleus of Excellence Support Program (*Pronex*), designed on the assumption that the resources for research were fragmented. It was intended to provide continued financial support only to highly competent research groups that had leadership and central role in their areas of expertise. Through three annual public calls-for-proposal in a national competition – published in 1996, 1997 and 1998 – a total of 206 nuclei of excellence were selected. At the time, the number of research groups registered in the CNPq Group Directory was about 10,000.[1] In addition to supporting only a small number of groups, Pronex promoted a considerable regional concentration, since 74% of the



We achieved significant results between 2003 and 2013: there were 87 priority programs with clear, institutionally-defined objectives and guaranteed budgets.

contemplated nuclei were located in the Southeast region; 17% in the South region; and only 9% in the North, Northeast and Central West regions.

It should also be noted that only academic groups benefited, leaving the technology institutes out of Pronex. Initially executed by Finep, the program was transferred to CNPq in 2000, when it had already lost its priority among MCT programs. As of that year, delays in the release of resources began, which forced CNPq to extend the execution times of the projects. Most of them had their duration changed from three to five years, without allocation of additional funds. Between 1999 and 2002 there were no other Pronex public calls.

The interpretation given at the time for Pronex's loss of priority was that it did not prevent the "dispersion" of resources for stimulus programs that took place in the research aid programs: 206 was considered an excessive number of centres of excellence in the country. This was one of the reasons for the virtual replacement of Pronex by the program *Institutos do Milênio*. In the year 2000 a public call was launched to select proposals for the new category of institutes, characterized as virtual networks of institutions, coordinated by a parent institution. The new program was financed with the credit balance of World Bank resources for the PADCT, with a counterpart from the National Treasury. From the 217 proposals submitted, only seventeen were selected, once more with a great regional concentration: fourteen proposals were from the Southeast region, two from the Northeast region and only one from the South region.

The negative reaction of the scientific community to the effect of the concentration promoted by Pronex and the *Institutos do Milênio* program led the CNPq to launch in 2000 a universal announcement to select projects presented by leaders of research groups, competing for financing in three categories of limit values.

The most important advance in the S&T sector in the late 1990s was undoubtedly the advent of funding for the science and technology sectors. Created as of 1999, the sectorial funds – closely following the Petroleum and Natural Gas Fund that had been established by law in the previous year – were soon seen as a way of ensuring more stable sources of S&T resources. MCT drafted several other legislative proposals that defined revenues for new funds, from taxes on the results from exploitation of natural resources belonging to the Federal Government to the industrialized products tax (*IPI*) on certain sectors and the tax for intervention in the economic domain (*Cide*), levied on the values that remunerate the use or acquisition of technological knowledge and the transfer of technology from abroad. During the course of the projects, there was a great mobilization of the scientific societies in the National Congress that contributed to the approval of the laws in relatively short periods.

The management model designed for sectorial funds was based on the existence of managing committees, one for each fund. Each committee was chaired by a representative of the MCT and composed of representatives from related ministries, regulatory agencies, academic and business sectors, as well as MCT agencies (Finep and CNPq). The managing committees have the legal prerogative to define the guidelines, actions and investment plans of the sectoral funds. Although this model allowed for the participation of broad sectors of society in the decisions on the application of resources, it resulted in poorly integrated management. From the fourteen existing funds in 2002, twelve were sectoral and only two were transversal (Infrastructure Fund and Green-Yellow Fund).[2] Therefore, FNDCT's re-composition through sectoral funds made it difficult to implement a comprehensive S&T policy, since several important sectors of the economy, as well as the areas of basic research, continued to have meagre resources.

Another important initiative of the MCT in the period 1999-2002 was the holding of the II National Conference of ST&I[3] in September 2001. It was preceded by the elaboration of the so-called ST&I Green Book, with information, analyses, diagnoses and challenges of the sector, based on the results of a broad debate coordinated by the MCT on the role of knowledge and innovation in accelerating the country's social and economic development. In addition to publishing the papers presented, the Conference also published the so-called S&T White Book, containing the challenges for the consolidation of the national S&T system and a set of objectives, guidelines and instruments for a national S&T policy.

2003-2013 period: implementation of more consistent S,T&I federal policies

In 2003, the government of President Luiz Inácio Lula da Silva began two initiatives that have greatly changed the S&T scenario in Brazil: it defined a national ST&I policy in 2004 and launched the S&T (Pacti) in 2007. The Pacti had four strategic priorities, guided by the national policy of S, T&I:

1. Expansion and consolidation of the national science, technology and innovation system;
2. Promotion of the technological innovation in the companies;
3. Research, development and innovation in strategic areas;
4. Science, technology and innovation for social development.

These priorities comprised 87 programs, all of them with clear objectives, institutions, targets and budgets. In 2011, at the beginning of Dilma Roussef's government, the national science, technology and innovation strategy (Encti) was announced, basically with the same priorities of Pacti, but without concrete goals and budgets.

In all four priorities, the results achieved were significant. The first one had the following main results:

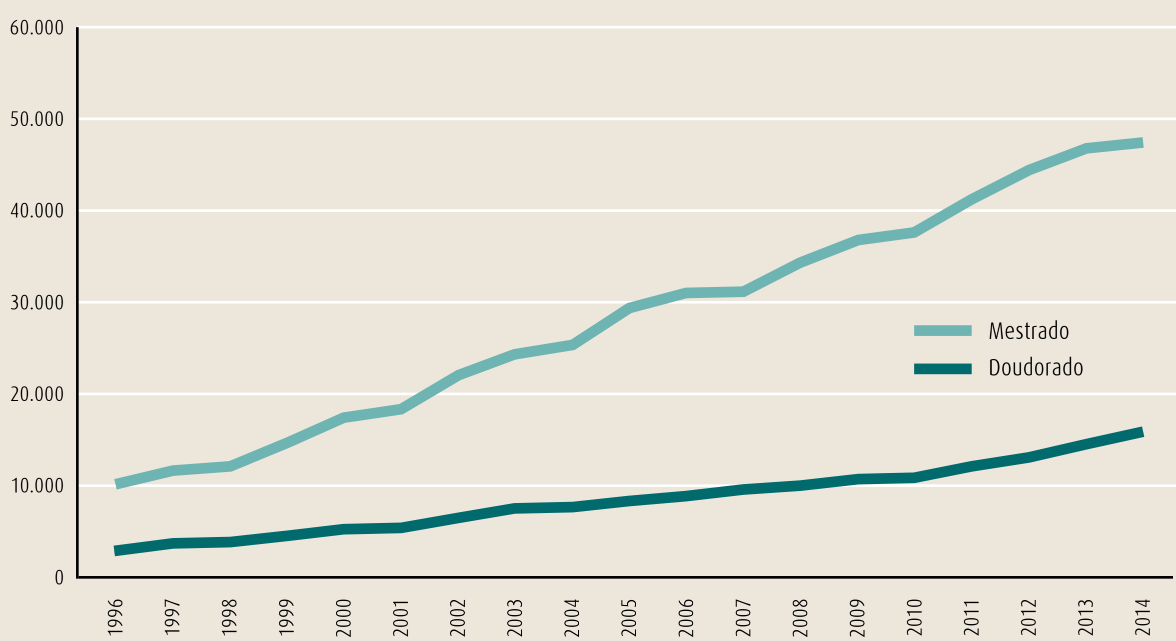
1. Great expansion of resources and financing modalities for scientific and technological research, with good geographic distribution;
2. Considerable increase in the number of scholarships and research grants from CNPq and Capes;
3. Expansion of actions and initiatives of international cooperation in S&T;
4. Strong increase in the articulation between the federal government and the states, which contributed to consolidate the national system of ST&I;
5. Completion of the high-speed Internet connection of all universities, technical schools and research institutions of the country through the new National Research Network (RNP).

One of the important results within PACTI's priority 1 was the considerable increase in the number of CNPq and Capes scholarships for students, from scientific initiation to post-graduation, as well as for research. The number of scholarships of the two agencies grew from around 80,000 in 2001 to around 200,000 in 2013. In that year, around 30,000 scholarships were related to the Science Without Borders program, created in 2011, with the aim of increasing exchanges with other countries.

The increase in the number of scholarships led to an expressive growth in the education of post-graduate human resources, with a master and doctorate degree, as shown in Figure 3. It is noteworthy that the number of masters and doctors graduated per year was multiplied five times within nineteen years.

In the second half of the 2000s, CNPq started to have public no-

Figure 3 | Evolution in the number of master's and doctorate degrees granted annually in Brazil from 1996 to 2014



SOURCE: COLETA CAPES 1996-2012 E PLATAFORMA SUCUPIRA 2013-2014 (CAPES, MEC). ADAPTED BY THE CGEE.
NOTE: THE DATA USED FOR THE GRAPHIC IS FROM TABLES M.TIT.01 E D.TIT.01 OF THE STATISTICAL ADDENDUM.

tices in programs to support projects in a wide range of research. The universal announcement, launched annually, was CNPq's largest initiative to support research projects of individuals and groups. Proposals can be submitted from any area of knowledge. At that time, the value of the universal announcement was substantially increased with funds from the FNDCT. CNPq also launched a wide range of calls for proposals on specific themes in a wide range of S&T areas, supported by resources from sectoral funds as well as from its own budget.

In the 1990s, an important initiative created, reinvigorated and expanded by CNPq is the Nucleus of Excellence Support Program (*Pronex*), which supports research centres formed by groups of recognized excellence and articulated in thematic networks. In 2008, the program was expanded with resources from FNDCT and implemented in partnership with state foundations for research support, which also provided counterpart resources and issued state-wide public calls.

The largest program in the history of CNPq, created in 2008, was the National Institutes of Science and Technology (*INCTs*). The Institutes of the Millennium program, created in 2001, aimed at forming research networks throughout the country, promoting scientific and technological excellence and strengthening research groups in any area of knowledge, including areas defined as strategic. For various reasons, the *Institutos do Milênio* did not reach importance and size as planned. As a result of Pacti, they gave way to the INCTs, characterized by an office in an excellence institution in research and teaching, acting in a thematic network with institutions in other regions of the national territory. The program, coordinated by CNPq, was organized and co-financed with Finep (FNDCT), the Ministry of Health, Capes, BNDES, Petrobras and State Research Support Foundations of São Paulo, Rio de Janeiro, Minas Gerais, Santa Catarina, Pará, Amazonas, Piauí and Rio Grande do Norte. The 2008 CNPq public call selected 122 INCTs, with resources of around R$ 609 million. The second public notice for the selection of INCTs, initially scheduled for 2012, was published in 2014. Only in 2015 the process of selecting about two hundred institutes, between new and existing ones, was completed. These INCTs bring together the best research groups in frontier areas of science and in strategic areas for the country's development and are helping to make our scientific and technological research more competitive internationally.

> There have been advancements in science in many areas, but technological innovation in Brazilian companies is still shy: less than 5% of our researchers work in-company.

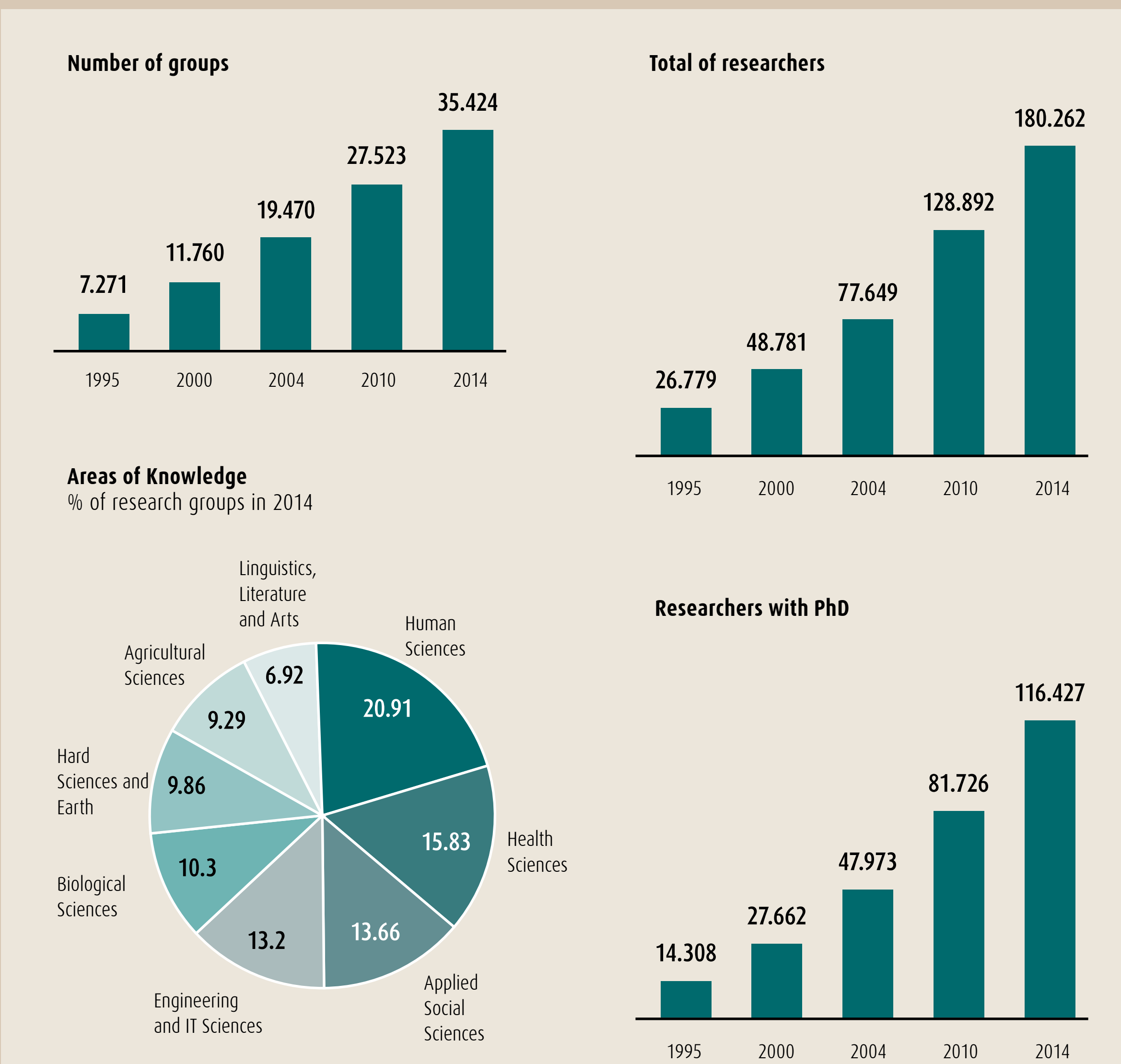
The financing of research and infrastructure projects was also done by Finep with FNDCT resources, primarily with selection of proposals through FNDCT/Sectoral Funds notices. While CNPq transferred resources to individuals, with commitments made through concession terms, Finep financed institutions through covenants. Among the notices are those included in the Infrastructure Modernization Program (*Proinfra*) of INCTs, financed with ST-Infra resources. It became part of the calendar of universities and research entities in the country, with a public call released in December of each year to select proposals in May-June. Since 2006 the Proinfra notices selected hundreds of proposals for a major improvement and expansion of the research facilities of universities and public entities throughout the country.

The actions of Pacti and Encti were decisive for the formidable expansion of the scientific community, which had been insignificant in 1960, thereby surpassing 180,000 active researchers in 2014 (Figure 4), of which more than 116,000 are PhDs. However, it is worth mentioning that our number of researchers per capita is still low: around one per thousand inhabitants, which corresponds to half the proportion in the industrialized countries. Continuing to expand the number of researchers will be one of the country's great challenges in the next decade.

Despite the great advance of science, technological innovation among Brazilian companies is still incipient. According to IBGE, among the 70,000 existing industrial companies in 2005, only 3% had released a new product onto the market. Less than 5% of Brazilian researchers work in companies. This situation is caused by the lack of a culture of innovation in the business environment, as well as the poor articulation of the industrial and S&T policies. Until 2005, the main instrument to support innovation in companies was Finep's line of credit with *TJLP* benchmark interest plus 5%.

Promoting technological innovation in companies became the main common priority of the Pro-

Figure 4 | Data on numbers of research groups and researchers in the directory of CNPq research groups (2014)

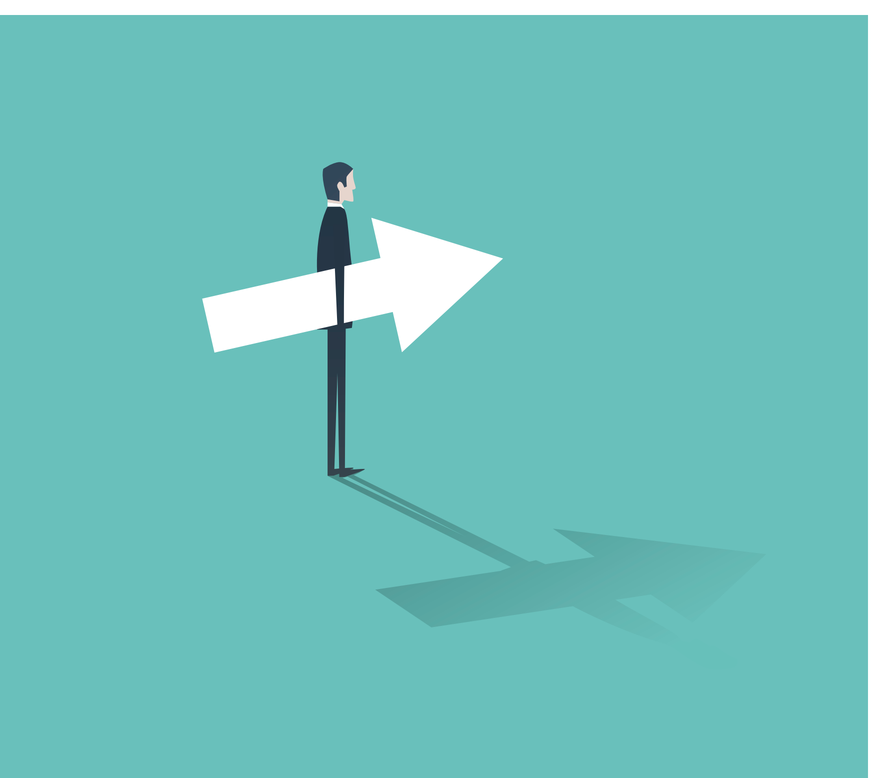


ductive Development Policy, of Pacti and Encti. The instruments created from the Innovation Act, approved in 2004, and the *Lei do Bem* of 2005 provided a new scenario for innovation in companies with a wide range of instruments to stimulate the creation of new companies based on technology, the so-called *start-ups*. The economic subvention, provided for in the Innovation Law, managed by Finep, made it possible for non-reimbursable resources to be granted to innovative companies through three programs: Finep's national call, the Business Research Support Program (*Pappe*) and the First Innovative Company Program (*Prime*), the last two in partnership with the states.

National subsidy announcements began to be released annually from 2006 on, focusing on different technological areas, with priority being given to those sectors most directly linked to the PDP, such as biotechnology, nanotechnology, STI, digital TV, pharmaceuticals and medicines, renewable energy and aerospace. Together with state partners, Pappe provided financial resources to small and medium-sized enterprises to develop innovation activities in the important sectors to promote local development. In parallel, Prime, which started in early 2009, conceded grants for *start-ups*.

In addition to the non-reimbursable operations already mentioned, Finep started granting support to innovation in companies through reimbursable operations, such as: Incentive Program for Innovation in Brazilian Companies (*Inova Brasil*) and *Juro Zero*. Replacing the former *Pró-Inovação*, Inova Brasil is a low-cost financing for research, development and innovation projects in Brazilian companies, such as a support to the PDP.

The National Program to Support Business Incubators and Technology Parks (*PNI*), created in 2004, was another important initiative to promote technological development and innovation in the micro and small enterprises, stimulating the implementation and consolidation of business incubators and technology hubs. Technology hubs, in turn, are complex economic and technological parks that foster and promote synergies in scientific and technological research and innovation among companies and scientific and technological institutions, both public and private, with strong institutional and financial support from the federal, state and municipal governments, as well as from the local community and the private sector. Finally, to complete the range of R&D support programs in companies, there is the RHAE- In Company



The cuts in the budgets of *CNPq* and *Capes* have reduced the number and value of available scholarships.

Researcher Program, a CNPq action to provide scholarships to encourage researchers, masters and doctorates to work in companies.

To foster the university-company interaction, the federal government implemented the Brazilian System of Technology (*Sibratec*), formed by three major networks: innovation, technological services and technological expansion. Sibratec (coordinated by the MCT, but with the active participation of several ministries and federal entities, such as Finep, BNDES and Inmetro) and Sebrae selected more than a hundred university-company cooperation proposals through public calls. In order to consolidate the process initiated with Sibratec, the government created the Brazilian Industrial Research and Innovation Company (Embrapii) in 2011, which has the mission of accelerating the process of industrial innovation, articulating national R&D among the companies, as inspired by the role of Embrapa. There is still a long way to go in this sector, but it is true that important steps have been taken in the right direction and there are clear signs that many entrepreneurs have been gradually incorporating the concept of innovation into their investment agendas.

While Pacti's priorities I and II were cross-sectional, covering all areas of knowledge and sectors of the economy, priority III (Research, Development and Innovation in Strategic Areas) focused on the development of thirteen strategic areas:

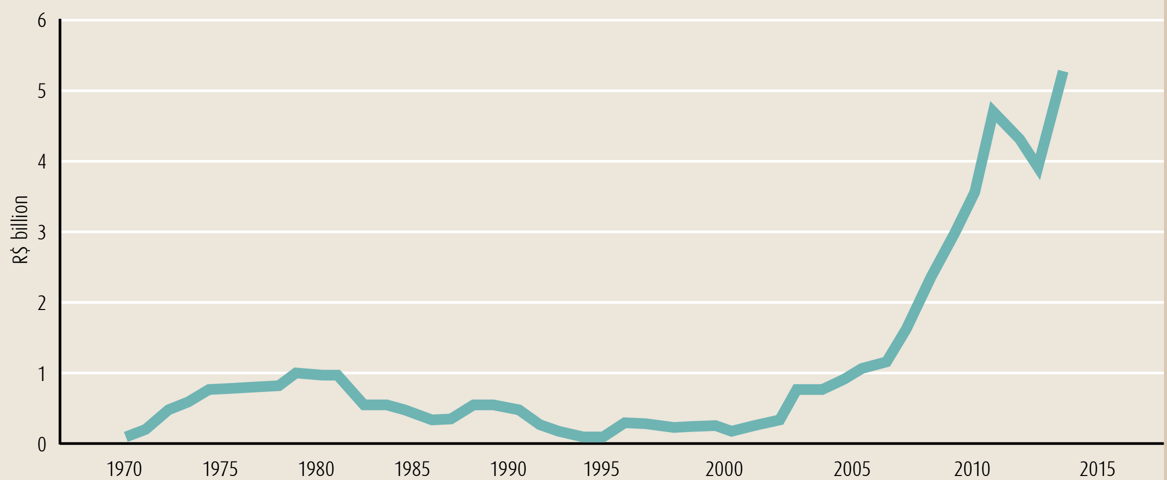
1. Areas bearing the future: biotechnology and nanotechnology;
2. Information and communication technologies (ICTs);
3. Health supplies;
4. Biofuels;
5. Electricity, hydrogen and renewable energies;
6. Oil, gas and coal;
7. Agribusiness;
8. Biodiversity and natural resources;
9. The Amazon and semi-arid region;
10. Meteorology and climate change;
11. Space program;
12. Nuclear program;
13. National defence and public safety.

In the STI scope, the main result was the return to develop microelectronics. Strategic due to its trans-versality in all industrial sectors, microelectronics was practically abandoned in the S&T and industrial policies of the 1990s. The National Microelectronics Program, implemented in 2003, was consolidated with the expansion of *CI-Brasil*, a program that is educating hundreds of integrated circuit designers in two training centres and eighteen centres and design houses throughout the country, and with the creation of the state company, the National Center for Advanced Electronic Technology (*Ceitec SA*) in Porto Alegre, linked to the MCT. Ceitec was established in 2008, with investments of MCT over R$ 800 million (from 2017), to build, acquire and install equipment for a project centre and integrated circuits factory – the first of its kind in South America.

Among the advances in the field of biofuels is the deployment of the Bioethanol Network and the creation of the Center for Science and Technology of Bioethanol (*CTBE*) in 2010. It was installed on the campus of the National Laboratory for Synchrotron Light, currently National Center for Energy Research and Materials, with the objective of contributing to maintain the Brazilian leadership in sustainable bioethanol production of sugarcane. The creation of the Brazilian Network for Research on Climate Change, instituted by MCT in 2007, should also be highlighted, the objective of which was generating and disseminating knowledge and technology, so that Brazil can respond to the demands and challenges represented by the causes and effects of global climate change and support Brazilian policies for prevention, adaptation and mitigation.

In the results of Priority IV of Pacti, the main highlights were the National Science and Technology Week and the Brazilian Mathematics Olympiad of the Public Schools. The Week, held since 2004, is the main initiative for the popularization of science and has had growing mobilization throughout the country. During the Week, usually on the second or third week of October each year, teaching and/or research entities promote activities to dissem-

Figure 5 | Historical evolution of FNDCT's financial execution, in constant R$ million, adjusted by the average annual IPCA



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inate science in its facilities or in public spaces.

Another important and successful program was the Brazilian Mathematics Olympiad of Public Schools (*Obmep*), created in 2005. In that year Obmep had the participation of around 10 million students and the number of enrolees has continuously been increasing. Since 2010, Obmep has had between 17 million and 19 million students enrolled in schools located in about 95% of the Brazilian municipalities, becoming a great program mobilizing the teaching of mathematics. It already has an impact on the improvement of science teaching in public schools.

The notable growth of disbursements by the National Fund for Scientific and Technological Development (FNDCT) contributed to the increase of federal resources for STI in the period of 2003-2010, as shown in Figure 5. This growth resulted not only from increased revenues from sectorial funds, but also from President Lula's decision to phase out its contingency gradually, a measure that has been practiced by the economic area since the creation of the funds, and which did not occur in 2010. Unfortunately, the FNDCT restrictions returned in the following years. As shown in Figure 5, the amounts disbursed in 2011 and 2012 decreased in relation to 2010. The peak observed in 2013 is somewhat artificial, since about R$ 2 billion were allocated to FNDCT for loans from Finep to companies and not for non-repayable financing, as in other years.

The expansion of federal resources for ST&I, combined with the numerous state programs, stimulated and made possible the gradual increase of the government investments; while legal measures and initiatives aimed at encouraging R&D and innovation activities in companies led to a substantial increase in R&D expenditure in research and development (R&D) and innovation. As a result, national R&D expenditures, combined with public (federal and state) investments with those of private companies, showed a steady and substantial growth in the period of 2003-2013. Expenditures on R&D regarding the gross domestic product (GDP), which were historically low in Brazil, or less than 1%, reached 1.24% in 2013. However, this rate is still very low when compared to industrialized countries, which are in the range of 3% to 5% of GDP.

Recent setbacks in the federal system of ST&I and challenges for the future

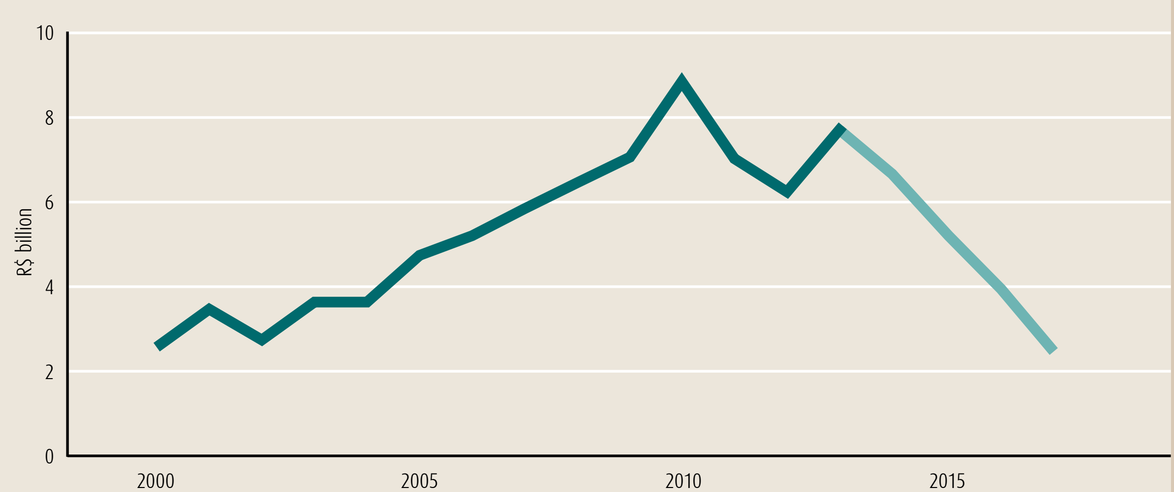
Despite the historical political, economic and social difficulties, Brazil has built the largest and most qualified scientific and technological community in Latin America, with more than 120,000 researchers with doctorates in the last four decades. National scientific and technological competence has not yet contributed more comprehensively to our development, but there are undeniable examples of success when the S&T area had resources and opportunities, with continued support from the federal government.

The most remarkable are Petrobras' deep-water oil exploration technology, which enabled the country to achieve self-sufficiency in oil; the design and manufacture of modern aircrafts by Embraer; the world leadership in agribusiness research by Embrapa; the domain of the complete cycle of production of enriched uranium to feed nuclear power plants. For the first time in the history of our country, there is an adequate "density of skills" in many areas of science and technology that is enough to contribute decisively to the achievement of ambitious development projects with domestic knowledge.

This encouraging scenario that has been built in the last four decades is threatened by the recent and huge setback in the federal S&T system. With the frequent change of MCTI ministers – five in the last five years – there have been changes in priorities and the discontinuity of many programs. FNDCT was once again subject to cuts, and almost all items in the MCTI budget were affected. To make the situation worse, the government that took office after the parliamentary coup in May 2016 merged the Ministry of Science with that of Communications, virtually declaring its extinction. As a result, the entire ST&I system was relegated to a lower level in the federal government hierarchy, causing further cuts in the budgets of all institutions in the federal system. The recent sharp drop in MCTI's budget is shown in Figure 6.

The cuts in the budgets of CNPq and Capes led to a gradual decrease in the number of scholarships, the amounts of which have not been adjusted since 2008. In addition, these agencies cannot normalize the releases for postgraduate courses and the various research programs, such as INCT and Pronex. Created in 2011, the

Figure 6 | Evolution of the executed budget of the Ministry of ST&I, in constant R$ millions, corrected by the average annual IPCA



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Science Without Borders program was phased out in 2016. Since reaching a peak of R$ 5.8 billion in 2013, the value of FNDCT has fallen in the following years to R$ 3.3 billion, R$ 1.6 billion, R$ 1.8 billion, reaching only R$ 1.7 billion in 2017. This decrease caused Finep's delay in the release of funds for projects approved in the various notices. Until recently it had not released funds for the projects approved in the Proinfra 2014 announcement.

This situation of dramatic budget cuts generated severe protests from entities of the S&T community, notably the Brazilian Society for the Advancement of Science (SBPC) and the Brazilian Academy of Sciences (ABC). They have expressed themselves publicly, warning the federal government, the National Congress and society about the risks to the future of the country. In an unprecedented move in 2017, there were 23 Nobel laureates that sent a letter to the President of the Republic, expressing concern about cuts in the S&T budgets and warning about the risks they represent. In another unprecedented move in 2018, the presidents of Capes and CNPq publicly expressed their concern about the budgets planned for 2019, which contained such deep cuts that, if implemented, will cause the cancellation of tens of thousands of scholarships.

The recent retrocession in the S&T scenario shows that the biggest challenge of the sector in Brazil is still the lack of State policies. Governments and priority changes make it difficult to maintain programs and actions, even the most successful ones. As Celso Furtado said, "underdevelopment is not a simple phase of transition to development, but a more permanent phenomenon, requiring a tenacious and prolonged political dedication to overcome it".

As we have seen, Brazil has only about one researcher per thousand inhabitants. For ST&I to become effective components of our economic and social development, it will be necessary to increase the quantity of scholarships and research, to expand the research community, to improve the quality of scientific production and the training of personnel at all basic, graduate and post-graduate levels.

It will also be necessary to increase industrial research significantly, as well as to insert technological innovation definitively in the productive process of companies. At the other end, it will be important to intensify the support programs for technology incubators and technology hubs; to increase the number of *start-ups* and innovative small - and medium-sized enterprises; and to create a new generation of technology entrepreneurs.

And not less important, it will be necessary to intensify the actions and initiatives of ST&I for the general public; to improve education at all levels – particularly science education in schools – to attract talents that demonstrate potential to develop as inventors, scientists, researchers and entrepreneurs; and to expand the quality and geographic distribution of science.

The current ST&I scenario makes this year's presidential elections decisive for Brazil's future. As a result, the SBPC sent to the presidential candidates a set of proposals:

> **It is necessary either to revoke Constitutional Amendment 95 – called the Budget Ceiling Law – or to promote its radical change in order to recover the State's investment capacity by allocating 2% of GDP for activities related to science, technology and innovation.**

1. To recreate a Ministry of Science, Technology and Innovation that is entirely dedicated to this issue, working with the state and municipal ST&I entities to articulate policy, and especially with the Foundations for Research Support, which are currently undergoing a serious crisis;
2. To revoke Constitutional Amendment 95 (the so-called Budget Ceiling Law) or promote radical change to it;
3. To stop further cuts to the FNDCT, promoting the gradual recovery of resources already subjected to contingency and make adequate use and permanent monitoring of all public funds to support research and development;
4. To recover the budget levels of investment in TS&I to that

of its highest level, during the period of 2009-2014;

5. To establish the goal of investing 2.0% of GDP in R&D resources in the coming years, with effective planning to achieve the goal;
6. To support and strengthen the programs and instruments essential to S&T (such as the National Institutes of Science and Technology - INCTs), the public call-for-proposals, and the Finep Infrastructure Program (Proinfra), as well as the consolidation and modernization of national multiuser equipment centres;
7. To comply with ongoing international agreements in the scientific area and support Brazil's participation in the major international research programs considered appropriate for the country;
8. To promote the effective and improved application of a new legal framework for ST&I at the federal, state and municipal levels, based on an evaluation of its operation. Remove or improve other legislation that makes it difficult to carry out scientific and technological research;
9. To develop a national S&T plan, with priorities connected to major domestic issues, and to mobilize national projects under a modern industrial policy to support processes and investments in innovation within companies. The National Council of Science and Technology (CCT) should be the articulating entity of this plan, which must emphasize the decisive role of state and regional ST&I structures;
10. To improve the quality of education at all levels, particularly scientific education, with the salary and symbolic valorisation of teachers of basic education; promote the use of research-based teaching methodologies and the appropriate use of the affirmative action policy;
11. To disseminate public administration that takes into account the results of scientific knowledge, respect for the environment and promoting social innovation and inclusion;
12. To defend national sovereignty on strategic issues such as Petrobrás; the exploitation of pre-salt, solar and wind energy sources; the national aeronautics industry; the Brazilian space policy; and the legal framework for the internet.

Considering the set of factors that characterize the current scenario of the country, these goals are coherent and feasible. They indicate the possibility of achieving a new development pattern in the next decade, with ST&I as essential elements for the sustainable development of Brazil. ■

Notes

1. For the triennium 1996/7/8, the Group Directory of CNPq had a total of 32,000 doctors, from which only 3,114 were engaged in projects under Pronex.
2. The portfolio of Funds is currently very close to that of 2002 and has been increased by two other Sectorial Funds.
3. the first National Science and Technology Conference, held in 1985, had the objective of including society in the definition of a science and technology policy for the nation. The 2nd Science and Technology Conference of 2001 emphasized the importance of technological innovation as an instrument for competitiveness. In fact, "Innovation" was thereby included in its name (www.cgee.org.br).

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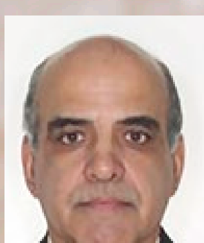
The role of Embrapa in the development and sustainability of Brazilian agriculture



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Heavy investment in human resources, with an extensive postgraduate program in Brazil and abroad, explains the success of Embrapa that today has 2,438 researchers, 86% of which hold a doctorate degree. It is the largest agrarian science training program in the tropics. Thanks to investments in agricultural science and technology, Brazil quintupled grain production between 1975 and 2017, while arable land only doubled. Genetic improvement of major crops, including soybeans, wheat, beans, corn, cotton, rice, fruits and vegetables were conducted. Similar work has improved the quality of beef, chicken and pork. All these advancements have contributed both to the country's trade balance and to reducing the food prices sold in the domestic market.

GILBERTO MARQUES/A2IMG

The creation of Embrapa and its model

The proposal for creating the Brazilian Agricultural Research Corporation (Embrapa) was approved by Law Nº 5,851 of December 7, 1972 and implemented on April 26, 1973. It was created as a state-owned company under private-sector law, replacing the National Department of Agricultural Research and Experimentation (DNPEA), directly linked to the Ministry of Agriculture. The option for the state-owned company model – an agency of indirect administration – was adopted in order to allow greater flexibility, efficiency and autonomy than the former DNPEA, in particular for fundraising and management of human and financial resources (Cabral, 2005).

Subsequently, the necessary structural measures were taken into consideration when creating its institutional model and planning system for the operation of the company. The structure, functions and attributions of its units were also defined at the national level, with its three types of research centres (for products, specific topics and ecoregional issues) and service units. Its role as the coordinating unit of the state agricultural research system was established.

The implementation of Embrapa was supported by the international agricultural research centres linked to the CGIAR Consortium and by international agencies, such as the Inter-American Institute for Cooperation on Agriculture (IICA), the Food and Agriculture Organization of the United Nations (FAO), and the US Agency for International Development (USAID), as well as by the decisive financial support through loans from the World Bank (IBRD) and the Inter-American Development Bank (IDB).

Two initiatives were fundamental in its institutional concept: the adoption of a model concen-

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trated on research and the capacitation of human resources. There were other components, such as proximity to the productive sector; administrative and financial flexibility; transparency and cooperation with other public and private organizations. It was within this context that the company focused its efforts on products and important topics for the food supply of Brazilians. Previous experiences in Brazil and abroad have shown that the dispersion of human and financial resources in regions, products and research lineshad produced limited results.

Embrapa invested heavily in the training of its human resources in the field of agricultural research in the main centres for excellence, especially abroad. This training brought the necessary institutional capacity to form international research networks, besides generating or adapting technologies to the country and its regions. It led Brazil to lead the world in the development of technological solutions for tropical agriculture (Embrapa, 2006).

Embrapa publishes an annual social balance sheet with studies of economic, social, environmental and institutional impact. An integrated planning system ranges from the formulation of long-term strategies to the individual agendas of each collaborator.

The planning culture

A culture of planning from its beginning is what stands out in the story of Embrapa, which would only become consolidated over time. It was fundamental for the company to establish priorities in its first decades in order to hire, train and allocate researchers, as well as to modernize and expand the infrastructure of laboratories and experimental areas.

In addition to the studies that supported the creation of Embrapa during the first two decades, several documents guided the implementation of a solid research and development (R&D) program to meet the demands of the Brazilian society. All the planning documents prepared during this period included national and regional priorities, essential for the company's deployment.

In the last twenty years, this culture has been consolidated with the adoption of a new strategic planning process based on conjunctural and prospective studies. The first conjunctural study for the research was prepared at the end of the 1990s with the assistance of the Institute of Administration Foundation (FIA) of the University of São Paulo (Ayres et al., 1990) that was essential for the preparation of the II Master Plan of Embrapa (PDE), covering the 1993-1997 period (Embrapa, 1994).

As of the beginning of the 1990s, after two decades of studies estimating its rates of return, Embrapa was questioned externally and internally about results from the institution's performance – especially regarding environmental and social impacts. These new demands arose mainly from the United Nations Conference on Environment and Development (ECO 92) held in Rio de Janeiro, and the dissemination in Brazil of a new type of document used to render accounts to society, called the Social Balance Sheet, focusing on effectiveness (use/adoption and impacts of results).

Seeking to meet these new social and environmental demands in the context of the Master Plan II, the company decided to reformulate its process of corporate performance management. In the second half of the 1990s,the Embrapa Evaluation and Results Awarding System - SAPRE (Embrapa, 1996) was developed, introducing an innovation: a systematic process of evaluation, linking it to the performance of teams and employees and, therefore, to the recognition and reward processes, with emphasis on results-based recognition.

In the efficiency criterion, the institutional performance evaluation of this system included a diverse set of indicators, such as meeting strategic goals, fundraising, improving processes and rationalizing costs. In addition, Embrapa introduced indicators of institutional performance evaluation based on efficiency criteria (production versus costs) and effectiveness (adoption and impacts). Since then, the results of the institutional performance evaluation have fed the subsequent process of awarding teams and employees, a decisive factor to establish the amount of resources related to recognition (Portugalet al., 1998).

Still in the 1990's there was another important milestone in the improvement of management: Embrapa's decision to adopt the Social Balance Sheet among its annual accounting documents to be disclosed to society, focusing on indicators of effectiveness (Embrapa, 2018a). With the Social Balance Sheet published once a year, the impact studies became more visible in addition to meeting the needs of SAPRE. This initiative helped to motivate the teams and mostly to improve the quality of the evaluation of technologies generated by the company.

Besides the managerial innovations of the 1990s that resulted from SAPRE and the Social Balance Sheet, it is also worth mentioning the effort made in the following decade to expand the scope of impact assessments. Until then, only the economic impacts had been highlighted. In the first half of the 2000s, the institution incorporated other indicators of effectiveness to the impact assessment process (environmental, social, and institutional indicators), moving from a one-dimensional approach to a multidimensional one, thereby consolidating a single methodology as a reference in the company (Avila et al., 2008).

A consolidated planning culture and a system of evaluation – with reward-based resultsand a commitment to the Social Balance Sheet– has been essential for Embrapa. This enabled the institution to establish itself as a company with content and solutions for agribusiness production chains that are capable of meeting government and sectorial objectives.

In 2014, the performance appraisal process was reformulated. The company's Board of Directors (Consad) established the integrated model for institutional evaluation, programme and team performance called Integro, which came into operation in 2015 (Embrapa, 2014a).

Processes that had previously been handled independently became integrated: management of strategic plans;institutional performance; research and support programming;management of people, recognition and reward processes; monitoring adhesionand impact assessment. Thanks to Integro, Embrapa is now able to manage its corporate planning, from the formulation of strategy to the implementation of the individual agendas of each collaborator.

At the same time, the institutional context and the multiplicity of topics covered required the company to build a strategic intelligence system, Agropensa, to analyse data and information relevant to agricultural research. The main product from this initiative was the preparation of the document "Vision 2014/34: the future of the technological development of Brazilian agriculture" (Embrapa, 2014b). This initiative was unfolded in the publication of another similar document, called "2030 Vision: the future of Brazilian agriculture" (Embrapa, 2018b).

This new process of intelligence, led by Agropensa, allowed the company to better ground its strategic plans. The Master Plan VI of Embrapa (PDE) was based on the first Vision document. The same should occur in the update of the PDE VII in 2019, following the recent publication of the document Visão 2030.

The great innovation in Embrapa's current strategic planning process is its integrated management, which in recent years has been linked to research, development and innovation (RD&I) programming, as well as to management and support actions. Backed by modern information management tools and fully administered in the logic of digital transformation, Embrapa reached a new level in the strategy management and corporate performance.

This extensive integration of processes, resulting from its performance management model (Integro), added to other improvements introduced in the other management tools (Ideare/Sisgp,project management,andGestec, management of technological assets, among others) resulted in substantial gains in efficacy, effectiveness and efficiency, both institutional (units) and in programming (macro-programs, portfolios and arrangements)[1], especially of its teams and employees.

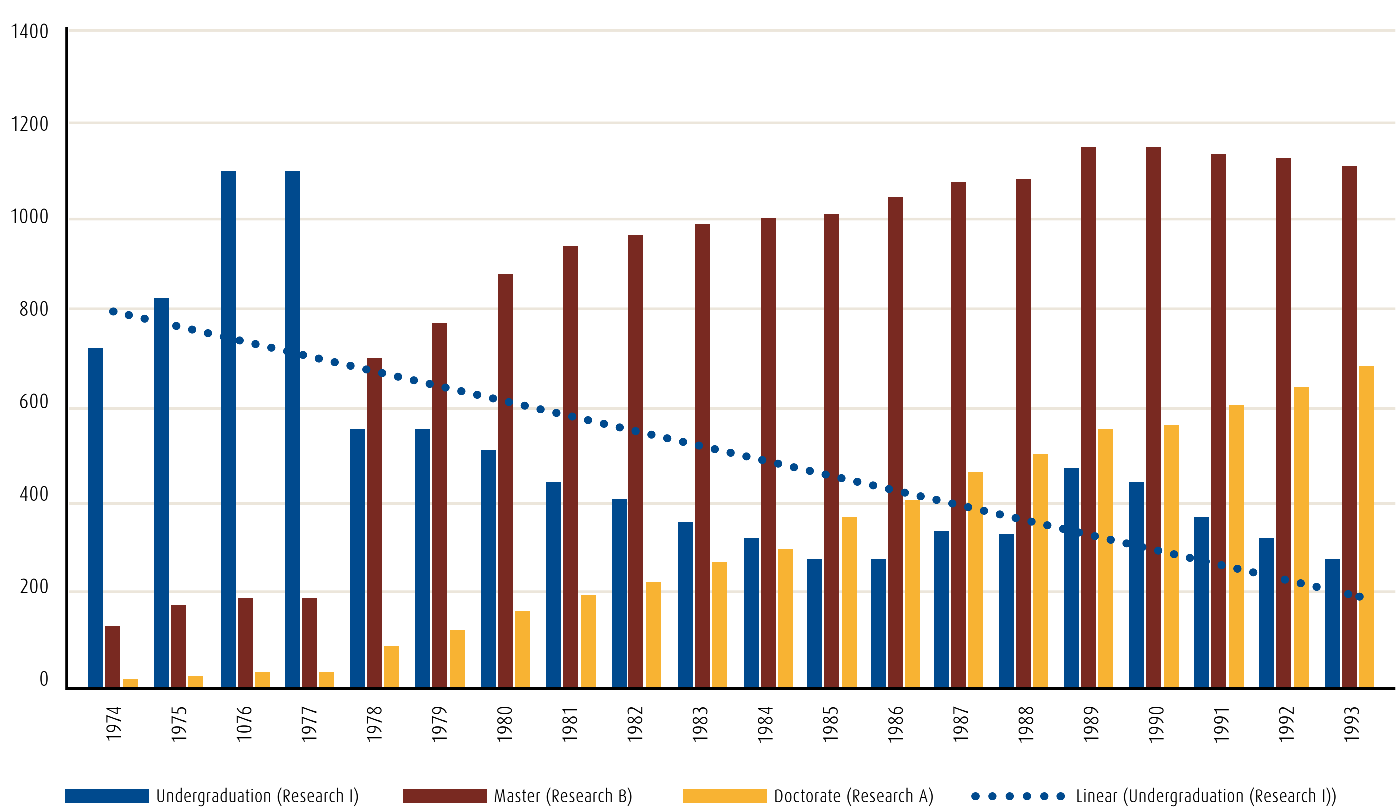
Integrated monitoring of planning and performance across all levels of the company has ensured that senior administrators and all managers have a clear view of each individual's role and contribution to corporate planning in order to meet the demands of the strategic plan. The performance of the company in recent years confirm the success of this integrated strategy and performance management, as detailed in the accounting reports submitted to the government auditing agencies, such as the Management Report.

Human Resources and Infrastructure

One of the major challenges faced by Embrapa, especially in its first decade of existence, was to overcome the various limitations pointed out by the working group that evaluated the situation of agricultural research within the DNPEA, thereby proposing the creation of the new company. At that time, the priority issues included the subject of human resources. There was a lack of staff with a leadership profile and workers with specialized training, especially those with postgraduate courses. In addition, the wage policy for staff involved in the agricultural research was unattractive (Embrapa, 2006).

Thanks to strong financial support from the federal government – including international loans from the Inter-American Bank and the World Bank – Embrapa implemented an extensive postgraduate training program in Brazil and abroad, involving the best universities in the world in agrarian and social sciences. The program was very successful. It soon allowed to reverse statistics on the education of researchers, which in the mid-1970s had only been a small number of postgraduates.

Figure 1 | Evolution of the academic education of Embrapa researchers – 1974-1993



According to the data presented in Figure 1, Embrapa's human resources situation was completely changed within twenty years. At the beginning of the 1990s, most researchers had master's degree, and there was increase in the number of researchers with doctorate degrees.

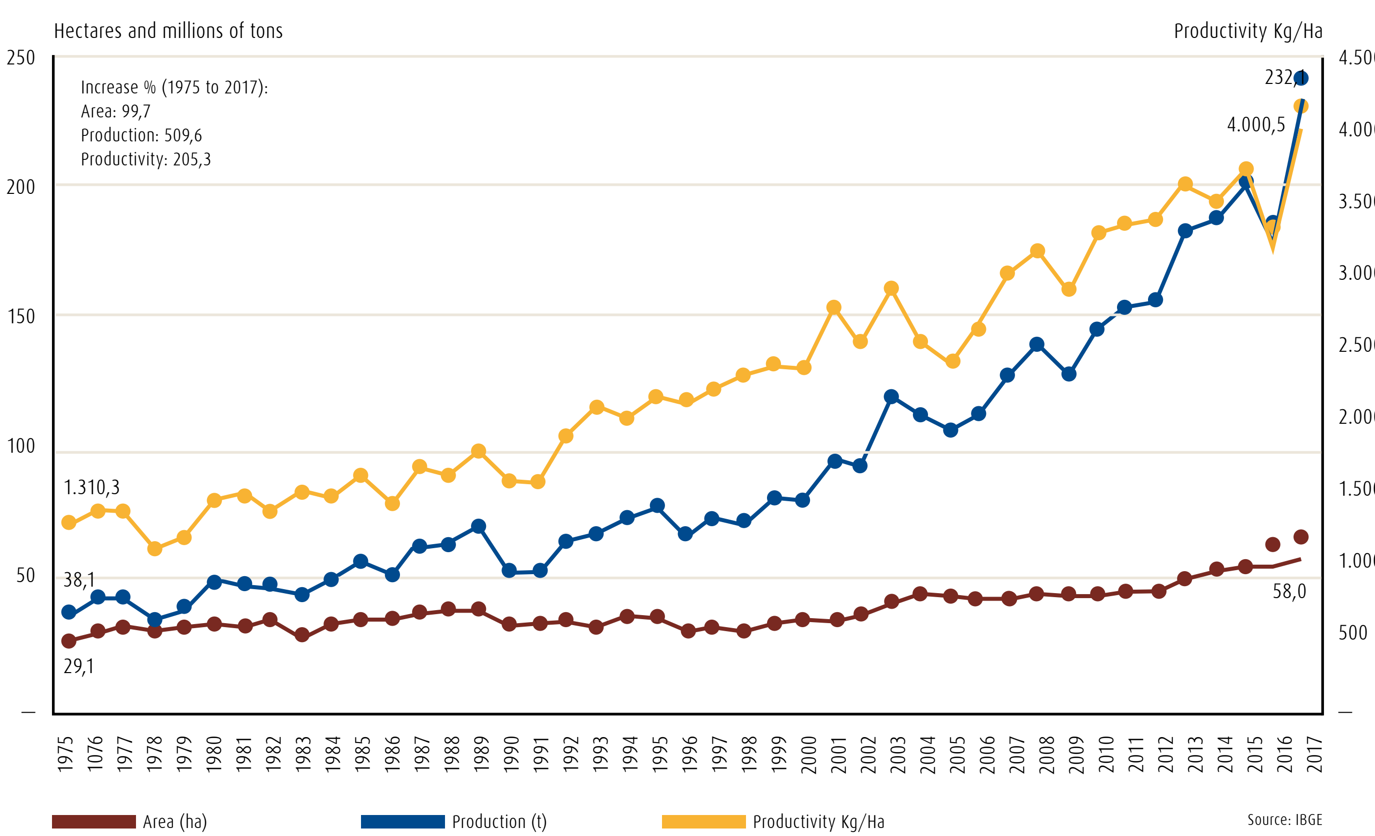
This process continues until today, focusing on the training of doctorates and post-doctorates. Currently, 45 years after its creation, the company has 2,438 researchers, of whom 86.3% have a doctorate degree and 13% a master's degree.

The strategic decision of investing massively in the training of researchers created the largest training program in agrarian sciences in the tropics. The program was decisive for Embrapa to assume its current position as leader of tropical agriculture research among developing countries.

Parallel to investments in human resources, Embrapa invested in the implementation and modernization of the research infrastructure, which initially had also been very restricted. Thanks to loans provided by the Inter-American Bank and the World Bank, together with strong accompanying support from the federal government, a large network of research centres was implemented.

More recently, other sources of funding have supported the company in improving centres and laboratories, both to avoid technological obsolescence and to maintain the international quality standard of its research services. It is within this context that the National Council for Scientific and Technological Development (CNPq), the Financier of Studies and Projects (FINEP), the National Bank for Economic and Social Development (BNDES) and the state foundations for the promotion of research stand out. It is also worth mentioning the large volume of resources of the National Treasury allocated for the modernization of laboratories and creation of new research centres in frontier regions (Mato Grosso, Tocantins and Maranhão) and in the area of agro-energy research. This investment was concentrated in the 2008-2012 period and was called Embrapa PAC.

Figura 2 | Evolution of the grain production, area and productivity in Brazil



The evolution of productivity and its impacts

In the analysis of this trajectory, one of the striking facts has been the central role of Embrapa in the productivity growth of Brazilian agriculture. Thanks to investments made in S&T by the federal government, Brazil quintupled the production of grains in the 1975-2017 period, while the area of arable land grew slightly more than 100% (Figure 2).

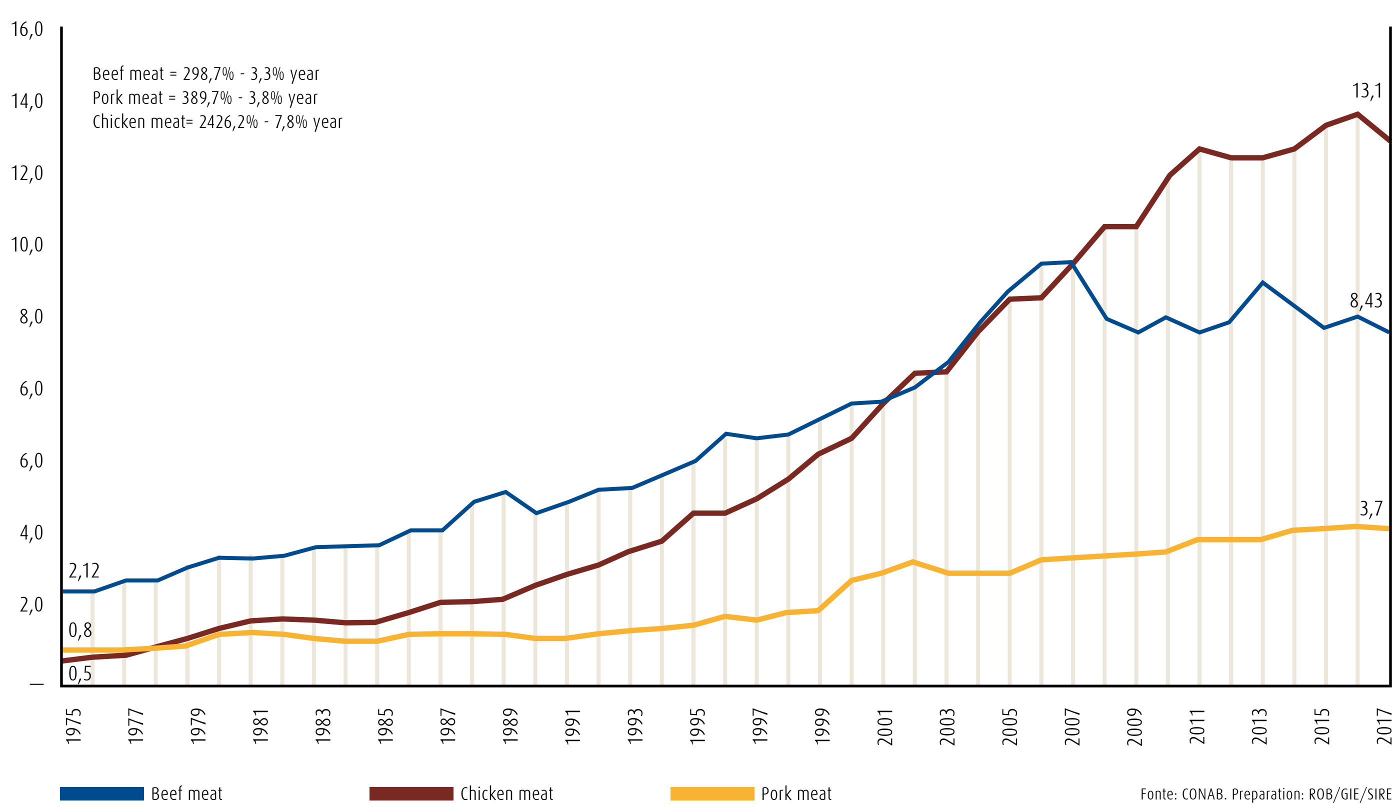
Especially in the first decades of Embrapa's performance, the main highlight in the production of grains was the genetic improvement of the main crops, especially soybeans, wheat, beans, corn, cotton and rice. Carried out in partnership with state agricultural research organizations and the private sector, this work generated productivity gains not only in grains and fibres, but also in fruits and vegetables. These gains can be seen in the vertiginous growth observed in the last forty years. They placed Brazil among the largest players in the world market for agricultural commodities.

This exponential growth was also observed in the area of beef, chicken and pork meat in the same period, as shown in Figure 3. The figures show high growth rates in production, with annual values higher than 3% in beef and pork meat and about 8% a year in the production of chicken meat.

Gains in the meat and by-products sector are reflected in the country's trade balance. Over the past decade, annual surpluses have surpassed US$ 70 billion, strongly associated with high S&T investments in domestic livestock. The main technological contributions of Embrapa occurred in nutrition, animal health and management.

The significant increase in the production and productivity of agriculture and livestock over the last

Figura 3 | Evolution of beef, chicken and pork meat production in Brazil



Fonte: CONAB. Preparation: ROB/GIE/SIRE

By conventional breeding or biotechnology, food biofortification increases the nutritional content of micronutrients, such as vitamin A, zinc and iron in bean cultivars, cassava and corn.

decades had a very important added impact for the Brazilian society, with the reduction in the prices of the basic food basket, as it appears in Figure 4.

If food shortages and imports were maintained in Brazil in the 1960s and 1970s, food prices would be at a much higher level today. Although this reduction is not only due to the research activity – since there were other important actors in the process – it is possible to state that a significant part of these social benefits can be attributed to the technological solutions generated by Embrapa and its partners. International partnerships are closely associated with the qualifications received by our researchers at the best universities in the world, as well as the scientific cooperation inherent to the R&D area.

Embrapa successful cases

Many successful cases can be seen in Embrapa's last 45 years. Perhaps the most important was the incorporation of the Cerrado into the Brazilian economy. In the Internet portal of the institution there is an extensive documentation about its main contributions.[2] We will highlight some of them, especially those which generated the greatest impacts and are included in the annual Company's Social Balance Sheet (Embrapa, 2017, 2018b). Embrapa's contributions in the formulation of public policies will also be highlighted.[3]

Highlights in RD&I

Embrapa has made important contributions in agro-industrial research, among them the improvement in the quality of products related to the biofortification of foods, a process used to increase the nutritional content of micronutrients, such as vitamin A and specific minerals (zinc and iron). These nutritional gains, introduced in cultivars already used by producers, such as beans, manioc and corn, are obtained by both conventional plant breeding and biotechnology.

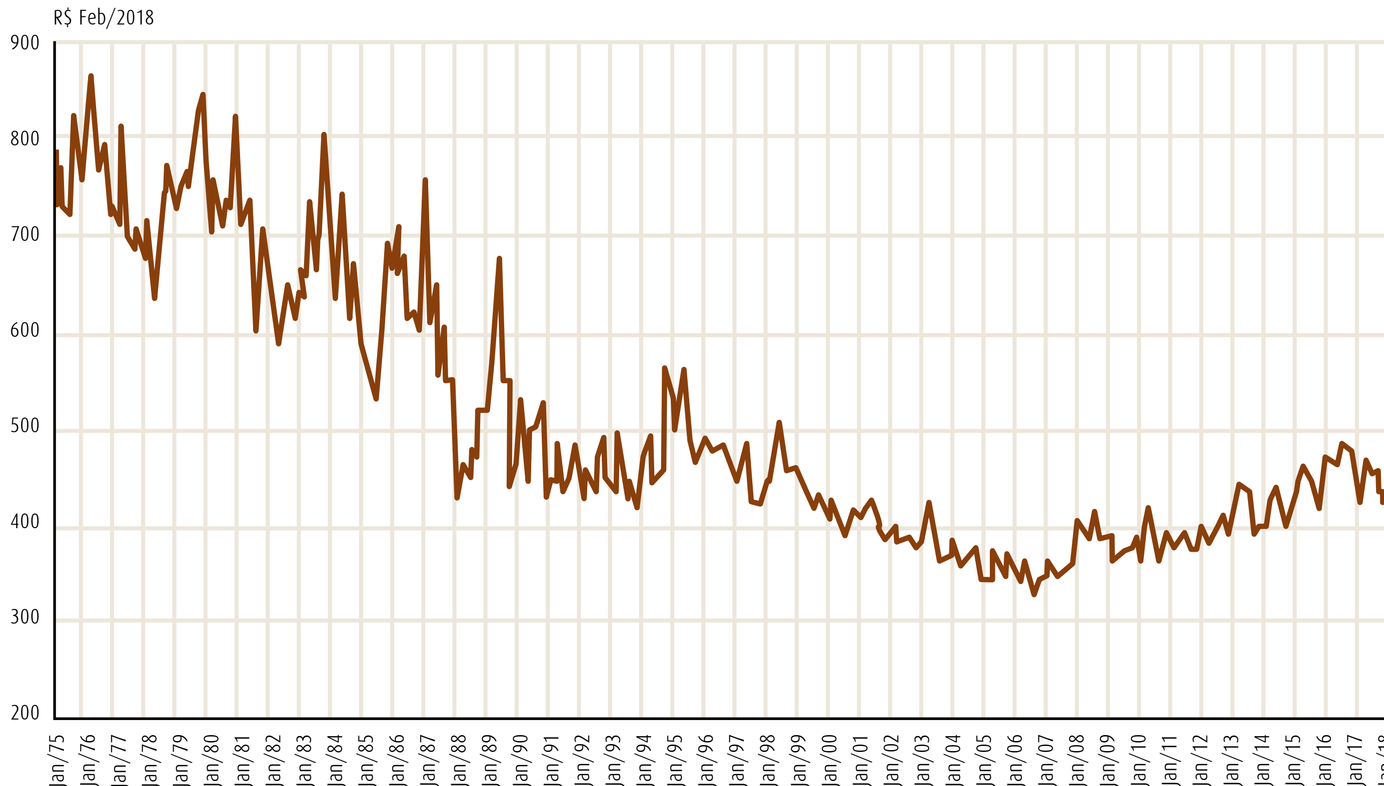
Embrapa's contribution to cotton producers deserves special mention, since itintroduced new varieties for the cotton regions of the country, especially in the state of Mato Grosso. Another highlight was the availability of coloured cotton cultivars of assorted tones, allowing small producers to add value to production,especially in the Northeast. In addition, technology generates income for the textile industry and contributes to retailers offering of differentiated clothing and fashion items.

Through research and adoption of sustainable forest management, Brazil has contributed heavily to modifying the traditional predatory exploitation of its forests. As a remedy, Embrapa has also collaborated for the sector to reach high levels of productivity with sustainability. Among the examples of this contribution is Modeflora, a system capable of providing the exact location of the trees in their environment, showing details of the terrain and hydrography, as well as other information essential for the correct management of the forest. Along the same line, forest planting management applications have been developed to support producers and technicians all over Brazil.

Embrapa has also participated decisively in the generation of technological innovations in fruit growing. Among the diverse contributions is the intense work of domestication of native species, such as guaraná, with important gains in terms of production and resistance to diseases. In cashew production, the development of new clones of precocious dwarf cashew tree made it economically viable to be produced, even in adverse climatic conditions.

Another outstanding example in the area of fruit growing was the availability of technologies that enabled Brazil to produce grapes even in the semi-arid region and to reap two mango harvests. Also noteworthy is the hy-

Figura 4 | Price of the Basic food basket in São Paulo Municipality (R$ Feb/2018*) – Jan/1975 Feb/2018



Source: DIEESE Preparation: ROB/GIE/SIRE * Monetary adjustment by IGP-DI

drothermal treatment of mango, which generated gains of more than R$ 1.4bn in exports in the last 25 years.

In the production of vegetables – a market that is very diversified – Embrapa has improved the production systems of the main species(potato, tomato, watermelon, lettuce, onion and carrot) fromwhich family agriculture accounts for more than half of production. Aware of its role in this segment, the institution also developed a new cultivar of cherry tomatoes, BRS Zamir, with a high content of lycopene, already present in 10% of the area planted with this variety in Brazil. In addition, the company introduced a Chinese technique of mushroom production cultivated by small farmers, with significant positive impacts on their production and consumption in the country.

In the area of grains there was an expressive growth of production and productivity. Embrapa and its partners played a decisive role in the genetic improvement of cultivars of the main grains produced in the country – rice, beans, corn, soybeans, wheat and sorghum – improving pest and disease control systems and creating new and more efficient management practices. As an example, the decisive role of Embrapa's research in the production of soybeans in tropical areas, previously limited to temperate regions, should be highlighted. More recently, there have been significant and innovative gains in wheat production, with cultivars adapted to the conditions of the Cerrado. Another relevant contribution of Embrapa are the barley cultivars, adopted by most Brazilian producers.

The company has sought to contribute to the increase of food production with environmental responsibility. We highlight the technologies made to reduce the use of agrochemicals, such as the integrated pest management and the use of biological control, such as biopesticides that fight corn pests without affecting the environment. Along the same line, more resistant cultivars have been made available to the water shortage areas, such as the cashew clone resistant to drought, which has led to substantial increases in income in the semi-arid region of Piauí.

Further to reconciling food production with environmental concerns, the company has been making new sustainable management practices available to farmers, such as those used in brazilnut production in the natural forests of the Amazon.

In addition to providing environmental conservation, Embrapa's technologies improved the living conditions of producers, especially the poorest ones, with basic sanitation. This is the case of the biodigester septic tank, which combines environmental gains and robust economic returns. Especially in the Semi-arid region, water cisterns and similar technologies allow for better coexistence with drought.

One of the most important users of technological innovations has been Brazilian cattle ranching. There was an intense modernization of the sector, with an increase in sustainable production and productivity. In addition to Embrapa, many institutions produce innovations for livestock, from genetics and nutrition to pest and disease control. They have increased the offtake rate of the beef cattle herd. The contribution of the company was more decisive in some areas, especially pastures: five of its forage cultivars account for almost 80% of the national market, making Brazil the biggest exporter of tropical forage seeds in the world.

Embrapa's research also contributed to the development of animals with lower fat percentage, which today represent the national herd standard. Moreover,

Biopesticides combat the pests of corn without affecting the environment, while new cultivars of cashews make them more drought resistant, expanding their presence across the Northeastern semi-arid landscape.

the doubling of the annual milk production in the last twenty years must be highlighted. This increase occurred not only with the expansion of the herd, but also with the increase of productivity, thanks to the incorporation of new technologies.

Regarding the improvement of the production process, one of the great contributions of the company was the integrated crop-livestock-forest system (ILPF), developed in the 1980s and 1990s to integrate livestock and grains. Having incorporated the forestry component since 2000, the new technique was already adopted in 11.5m hectares in 2016 (Embrapa 2017) and now exceeds 15m hectares according to the ILPF network.

Transfer of technologies and knowledge

Embrapa technologies reach distant and rural producers through various initiatives, involving field days and caravans all over Brazil.

Covering a broad range of topics, these initiatives havethe additional purposes of validating and transferring technology. They also serve to strengthen interinstitutional partnerships; capacitate professionals as multipliers that capture resources;as well as partake in the broadcasting of radio and television programs.

Still in the scope of knowledge transfer, Embrapa ensures open access to information, such as Embrapa's Open Access to Scientific Information (Alice), which is the eighth most accessed among the 51 Brazilian scientific repositories. Another strategy has been the preparation and dissemination by the media of technical videos and programs such as Prosa Rural (Rural Chat), broadcast free of charge through more than 9,000 radio stations in the country, and the TV show Dia de Campo na TV (TV Field Day) with an audience of 5.7m viewers.

Similarly, Schulz (2018), a professor at Unicamp, says that Embrapa is the 11th in the ranking of 144 Brazilian governmental institutions in scientific production. In the citations per article criterion, the same author points out that Embrapa presented an average of 11.27 in the 2009-2013 period, emphasizing the importance of international partnerships, especially that with the US Department of Agriculture, with an average of 42.42 citations per article.

Participation in the formulation of public policies

In addition to the mentioned technological successes and performance in the technology transfer, Embrapa has participated in the drafting and enactment of laws, decrees, normative instructions, plans and programs at the international, national, regional, state and municipal levels. This participation – as seen in the Social Balance Sheets 2014 and 2015 – can be seen in more than a hundred public policies, demonstrating that the impact of this work goes far beyond the effects of technologies in increasing productivity, job creation, cost reduction or value aggregation in the productive sectors traditionally measured.

Embrapa's most recent contributions to public policies include: (a) the Low Carbon Agriculture Plan to reduce the emission of greenhouse gases by the agricultural sector (ABC Plan); (b) the Fishery Control System, focused on the sustainability of the Pantanal; (c) the Environmental Licensing System, which expedites assistance in the states, including the requirements of the new Forest Code; (d) the Public Policy for the Integration of Crop-Livestock-Forests (ILPF); (e) the Delimitation of Matopiba,[4] which opened the way for the implementation of public policies in the region; and (f) the Agricultural Climate Risk Zoning (Zarc).

Embrapa's social profit

Although producing private goods and services that can be sold in the market, Embrapa's main social role is to produce public goods and services. Unlike private research, beneficiaries do not pay for the use of these goods and services.

Public institutions dedicated to agricultural research like Embrapa can generate profits from the sale of products (seeds, seedlings, animals, etc.), services (laboratory and soil analysis, maps, etc.), or even patents (equipment, machines, etc.), but they only cover a small part of their costs.

When analysed from the accounting and financial perspective, this lack of profit is sometimes interpreted as a loss. But it is counterbalanced by the social benefits these institutions provide. There is social profit to the extent that goods and services generated by science and technology institutions are successfully adopted by customers and users, together with their associated economic, social and environmental benefits. With this positive balance, a possible dependence on the National or State Treasury is widely compensated.

This concept of social profit, used by Embrapa in the preparation of its Social Balance Sheet since 1997, refers to the socioeconomic benefits generated annually, compared to the net operating revenue of the company. The estimate comes from monitoring and measuring the impacts of a sample of public goods and services made available to the society. This continuous and systematic monitoring of impacts has been done for more than two decades and shows positive social balances sheets every year. It is through such monitoring that Embrapa has demonstrated the fulfilment of its social role.

Since the 1980s, Embrapa has conducted studies to estimate the social results from its operations, i.e. the economic impacts generated by the adoption of the technologies, products and services (net additional revenue generated). At first, these studies sought to estimate the internal rate of return of the investments, relating the economic benefits over a certain period to the costs of the technologies that generate such benefits (Avila et al., 2005, for example). From the initial studies, dozens of works were carried out in the 1980s and 1990s, involving technicians from Embrapa and national and international consultants. The results indicated rates of return of 30% to 40%, proving that the resources invested in the company were beneficial to Brazilian society. Such rates are close to the results of studies that evaluated the return on investments in agricultural research in other parts of the world (Alston et al., 2000).

With the publication of the Social Balance Sheet, based on a methodology disseminated by the Brazilian Institute of Social and Economic Analysis (Ibase) since 1997, Embrapa began to monitor the impacts of a sample of 115 technologies incorporated in the Brazilian agricultural production chains, as well as of its own cultivars and those of its partners and used by producers – especially in the cases of cotton, rice, beans, corn, soybeans and wheat.

Several initiatives, involving radio, television, internet, field days and caravans, take Embrapa technologies to extension programs and rural producers, reaching millions of users in all regions of the country.

This monitoring of benefits and costs has allowed Embrapa – a world pioneer in this procedure among S&T institutions – to estimate its annual social profit (economic impacts plus values of social and labour indicators) and relate it to its annual operating income.

The most recent results, published in the Social Balance Sheet of 2017, show a social profit of R$ 37.18bn. When this profit is related to Embrapa's net operating revenue, the ratio is 11.06. This indicates that, considering only the annual revenue and social benefits in a sample of technological solutions made available to the society, the annual return was eleven times higher than the investment.

When using the traditional indicator of investment return analysis, which is the internal rate of return (IRR), the results also show a high social return. The estimated IRR was 36.1% based on the time series of economic benefits of Embrapa products. This rate of social return refers to the average returns of investments made in the generation of technologies monitored and evaluated since 1997.

Besides social profit, there are other ways to measure Embrapa's contribution to society. In its mission to generate and disseminate knowledge, the company stands out as the 8th Brazilian institution in volume of scientific production, according to the international database Web of Science. The scientific articles produced by Embrapa received more than 33,000 citations in the last five years, which shows their impact on the advancement of knowledge.

More evidence of impact can be seen in the technical-scientific publications made available by Embrapa on the Internet. In 2017, access controls to its repositories registered 24.5 million downloads, made mainly by public and private agents of technical assistance and rural extension and by rural producers. Considering the period 2011 to 2017, the total of downloads of Embrapa publications reached 74.9 million.

Regarding the environment, there were several relevant contributions in the recent years, thanks to the adoption of Embrapa technologies. Taking into account only the most emblematic cases – the Low-Carbon Agriculture Program (PlanoABC), the adoption of biological nitrogen fixation (BNF) in soybean crop, and the integrated system of crop-livestock-forest production (ILPF) – the reduction of carbon emissions in the 2016-2017 harvest was around 65 million tons of carbon equivalent, of which BFN contributed 30m and ILPF 35.1m (Embrapa, 2018a).

If other technologies that are part of the ABC Program, such as the recovery of degraded pastures and direct planting system are included, these environmental gains are even greater. The technologies of Embrapa and its partners have had positive environmental impacts, contributing to Brazil's large-scale implementation of the international commitments made at the Conference of the Parties (COP), which is the supreme decision-making body under the Convention on Biological Diversity (CBD) to reduce the emission of greenhouse gases.

There is numerous, measured and documented evidencethat Embrapa is a success story of Brazilian public administration, considering its economic, social and environmental impacts. The institution fulfils the role of generating public goods that compensate the investments it receives. ■

Notes

1. The macro-programs, portfolios and arrangements are programatic figures that have been used by Embrapa to join its research, development and innovation projects.
2. – https://www.embrapa.br/grandes-contribuicoes-para-a-agricultura-brasileira?link=acesso-rapido.
3. – http://bs.sede.embrapa.br.
4. Acronym of the initials of the states of Maranhão (MA), Tocantins (TO), Piauí (PI) and Bahia (BA).

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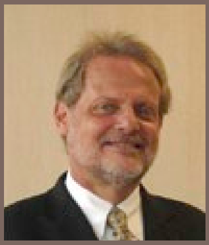
The role of the Brazilian Navy

New materials, special alloys, electromagnetic spectrum control and mastery of uranium enrichment technology are some of the scientific and technological challenges the Navy faces in close collaboration with universities and companies. All this makes up an extensive and complex system that benefits everyone. Built in partnership with France, the project for the first Brazilian submarine powered by nuclear propulsion is in the detailing phase. Science, technology and defence policies are inseparable.

Introduction

Throughout its history, the Brazilian Navy has recognized the strategic value of science, technology and innovation (ST&I) for defence and has used such instruments for its tactical and operational improvement with increasing intensity. The evolution in the systematic use of ST&I for training personnel, developing equipment, and means of deploying navy and marines led to the creation of the "Science, Technology and Innovation Strategy of the Navy".[1]

The elaboration of this strategy was based on the analysis of the national ST&I strategies of the United States, France and Brazil, as well as the study of several documents defining public policies, such as the National Defence Strategy[2], for example. The information thus obtained led to a ST&I action plan, based on the triple helix model and topics for action that could meet the Navy's needs.



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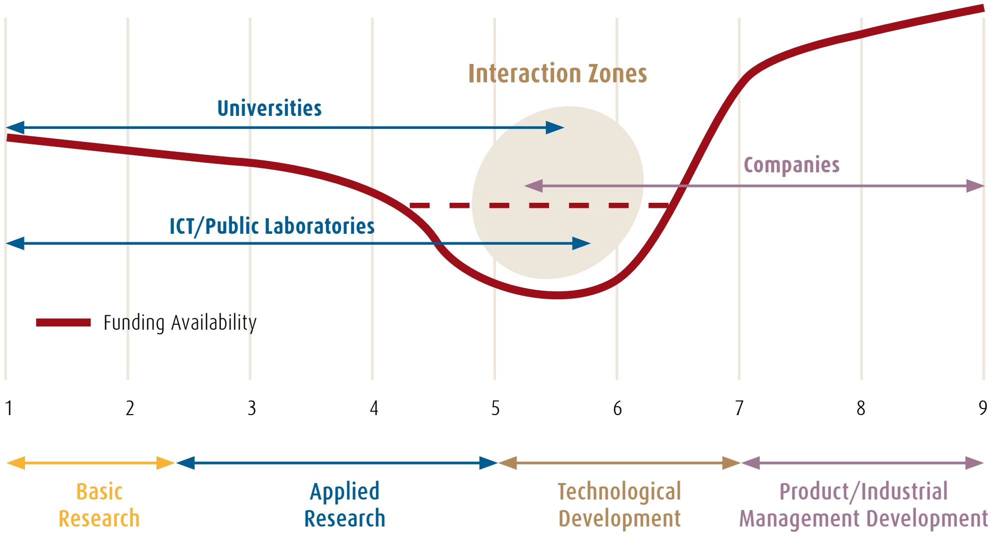
The model symbolizes the dynamic evolution of the interactions between academia, corporations and government, through upward spirals. Interactions occur throughout the evolutionary chain through the exchange of science, technology, research and development. The mode of operation is based on research and development activities in partnership with universities, research centres and technological institutes – scientific-technological institutions – and companies, with special attention to dual technologies.

Figura 1 | Steps of technology development



The different steps of this mode of operation, shown in Figure 1, involve different combinations of partners, depending on the level of technological readiness (TRL) of each stage. The region demarcated as "zone of interaction" is also known as the technological "death valley", since most of the technologies in this zone cannot reach readiness and are then abandoned. The Brazilian Navy has paid special attention to technologies of its interest that belong to this TRL range, which are at the risk of never materializing.

Besides establishing the necessary institutional policy in the area of interaction of the chart, involving different partners, the mode of operation defined by the ST&I strategy also considers the financial resources, mainly due to the variation of the types of funding available, according to the increase in the technological readiness level. The universities interact with Navy science and technology institutions in phases 1-3, dedicated to basic and/or applied research. Typical of technological development, phases 4-7 involve these institutions and companies, the latter in the stages of testing and prototyping. From this stage onward, companies are responsible for the production scale. There is a particular interest in the leverage of the country's industrial defence base, using all the federal and state government instruments and legal frameworks to stimulate innovation, focusing on products, processes and services of interest to the Navy. With regard to the concept of topics for action, created to bring together different lines of research around operational applications of interest, the Navy established the following nomenclature, with no priority sequence: (a) command, control, communications, computing, intelligence, surveillance and reconnaissance; (b) combat performance; (c) naval, air force and marine platforms; (d) operational environment; (e) chemistry, radiology and explosives; (f) cyber defence and security; and (g) nuclear and energy.

The definition of a modern ST&I strategy is combined with an effort to rationalize the use of the Navy's human and material resources, which resulted in the creation of the General Directorate for Nuclear and Technological Development of the Navy (*DGDNTM*), encompassing the nuclear, science and technology sectors. This organizational change was preceded by a study of the organizational structures of many institutions, such as the other security forces, Petrobras, Embrapa, Office of Naval Research (ONR, from the United States) and *Direction Générale de l'Armement* (DGA of France).

The DGDNTM nuclear and submarine project sectors are located at the Navy Technology Centre in São Paulo (*CTMSP*), one part in the University of São Paulo (USP) campus, and the other part in the Aramar Nuclear Industrial Centre (*CINA*) in Iperó, 120km from the capital. The CTMSP headquarters in USP holds the project and offices of the Submarine Development Centre (*CDS*), as well as the testing laboratories of the Navy Nuclear Development Board (*DDNM*).

The Navy has permanent offices for prospecting technology in Brazilian public universities, with which it maintains very important partnerships.

At the CDS, the French technology of submarine construction is assimilated and put into practice in the projects; at the DDNM, the Nuclear-Electric Power Generation Laboratory (*Labgene*) project is being developed, and its facilities are being built in Aramar. CINA acts on the uranium enrichment part and the production of fuel elements from the nuclear fuel cycle. To that end, CINA includes the Uranium Hexafluoride Plant (*Usexa*), the Isotopic Enrichment Laboratory (*LEI*), the Materials Laboratory (*Labmat*) and the Laboratory of Testing of Propulsion Equipment (*Latep*), in addition to the Labgene.

The other ST&I activities are concentrated in the Rio de Janeiro Navy Technology Centre (*CTMRJ*), composed of three research institutes: the Centre for Naval Systems Analysis (*CASNav*) and Navy Research Institute (*IPqM*), in the city of Rio de Janeiro, as well as the Institute of Ocean Studies Almirante Paulo Moreira (*IEAPM*) in Arraial do Cabo.

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In addition to the two centres, the DGDNTM incorporates the General Coordination of the Nuclear Propulsion Submarine Development Program (COGESN) and the Naval Agency for Nuclear Safety and Quality (*AgNSNQ*), the first one in charge of the construction of a submarine with nuclear propulsion (SN-BR) and the second one is responsible for its licensing and inspection. The DGDNTM is also responsible for two strategic programs of the Navy and the country: the Submarine Development Program (PROSUB) and the Navy Nuclear Program (PNM), State programs with huge technological impact.

This article is structured as follows: in section II we will present some products developed in the technological centres of the Navy that have been successfully tested and used; in section III we will approach PROSUB, which is about to complete the construction of its first conventional submarine; Section IV will describe the PNM, since its creation; and we will conclude with the final considerations.

Successful projects

Several successful Navy ST&I projects are examples of the use of the "triple helix" model, as they involve partnerships among universities, Navy science and technology institutions, companies and government sectors. They resulted in products – some of which are tradable – that have met the demands of the Brazilian Navy.

Partnerships with universities have been very important for the Navy, which set up and maintains technological prospecting offices in four of them: UFRJ, UFF, FURG and USP. Established about sixty years ago, the latter represents the oldest partnership with academia and remains in force with the creation of the first naval engineering course in Brazil.

Among the successes, the carbon fibre production project used in ultracentrifuges, developed in the CTMSP, is especially important. Through the development of these carbon-based materials, ultracentrifuges designed by the Brazilian Navy can operate with high efficiency and safety. Thanks to the dominance of the carbon fibre production process, the Brazilian Nuclear Industries (INB) already operates seven ultracentrifuges cascades manufactured in the country, supplied by the Navy. CTMSP itself is also a user of this material in its cascades to produce the LABGENE fuel and, in the future, the nuclear-powered submarine (SN-BR) to be built under PROSUB. The development of special alloys allowed the fabrication of several metallic parts, used in the nuclear technologies employed in the CTMSP.

The project of sensors for monitoring the electromagnetic spectrum and the detection/classification of radar emissions from aircraft and vessels (*MAGE*), developed by the IPqM, provided the Navy with an electromagnetic spectrum monitoring system that can detect many types of threats during operations, such as hostile broadcasts and approaching radar-guided missiles. The MAGE "Defender" is installed aboard escort ships and is constantly evolving. Brazilian industry received the technology to build the hardware and supply the equipment to the Brazilian Navy, which remains responsible for the software and the embedded intelligence.

The design of electromagnetic radiation-absorbing materials

Brazil has developed its own technology to monitor maritime areas of interest, where it can be used in search and rescue operations, and combating illegal fishing and contraband.

for radar camouflage (also of the IPqM) reduces radar reflection of ship structure parts, thereby increasing their stealth. Developed initially as paints, these materials are produced in Brazil and are part of the painting scheme of the periscopes of the Tupi-class submarines, operated by the Brazilian Navy. At the IPqM, the development of these materials continues with the search for absorption in different bands of the electromagnetic spectrum and its utilisation in different venues, such as plates and elastomeric sheets that will allow of applications in structures with larger dimensions.

The project of tactical control systems for naval operations of the SICONTA family – now in operation in the Brazilian Navy – was born from the work of the IPqM. Its development was based on simulators for the tactical training of the students of the Almirante Marques de León Training Centre (*CAAML*). It is a comprehensive surveillance system that presents to the operator the tactical picture of the maritime arena where the naval environment is located, thereby providing maritime situational awareness and allowing network-centric operation when tactical information is shared by more than one ship. In addition to the technology transfer to Brazilian industry (the current system supplier to the Brazilian Navy), the continuous development of SICONTA resulted several derivative products, such as the Centre for the Integration of Sensors and Electronic Navigation (*CISNE*) and the System of Tactical Simulation and Training (*SSTT*), which today is in its third version. These systems can operate interconnectedly in real time.

The Maritime Traffic Information System (*SISTRAM*) is intended to monitor vessels in areas of interest and may be used for many purposes. It is a tool developed by CASNAV to support decision-making in search and rescue operations (SAR), which can be used to monitor illegal fishing and combat piracy, drug and gun trafficking. SISTRAM is compatible with other existing systems in the world, allowing quick localization and activation of nearby vessels in case of maritime emergency. Its flexibility allows data to be fed from various sources according to the available communication network. It is composed of a geo-referenced viewer, a management module and a data analysis module.

IEAPM developed a natural biocide-based anti-fouling paint. The project was started with the collection, identification and extraction of substances from marine organisms in Arraial do Cabo (RJ) and subsequent test of their antifouling activity in the laboratory and in the field, which was a joint work between the Federal Fluminense University (UFF) and the IEAPM. The substances with the best performance were selected to be synthesized in a laboratory of the Federal University of Rio de Janeiro (UFRJ). The production process has already obtained a patent in the United States and the paint is being produced in Brazil by domestic industry.

It is clear to see that all the projects described benefited from the existence of a scientific-technological community – both in the Navy and beyond – as well as from a Brazilian industrial base. This is the result of years of investment in the education of qualified staff in the various areas of ST&I.

The Submarines Development Program

The Navy started submarine operations in 1914. Since Brazil did not yet have the technology to build these complex naval vehicles, the first submarines were Italian. Subsequently, the Navy operated American submarines of the Guppy class and British ones of the Oberon class.

The construction of submarines in Brazil began with the Navy Refurnishing Program (*PRM*) in 1979, which opted for the German IKL 209-1400. Tupi – the name of a submarine class – was built in Germany with the participation of Brazilian engineers who acquired the technology involved. The other submarines of this class were built in Brazil: Tamoio, Timbira and Tapajó, followed by the Tikuna – the name of a class that incorporated a series of innovations proposed by the Brazilian engineers. All of them continue in operation.

With the transfer of the German technology of the IKL, several Navy engineers acquired the necessary basis for designing and constructing submarines, a task of high technological complexity, as can be seen in the chart. This base allowed the development of two classes of domestic submarines: S-NAC I (conventional) and S-NAC II (nuclear). In 1990, due to unavailability of resources, the S-NAC program was paralyzed.

The difficulty level of building a nuclear submarine is shown in figure 2.

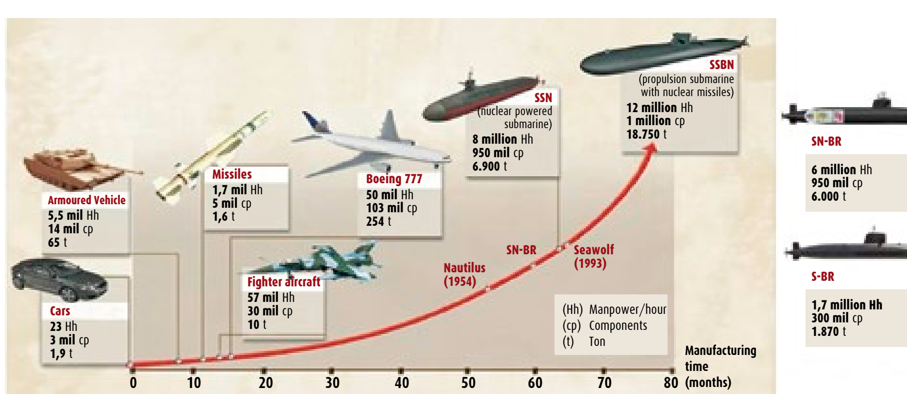
The Figure does not include the process of obtaining the nuclear fuel, the cycle of which the Brazilian Navy also had to master, since it is not a commercialized material.

In order to overcome difficulties inherent to the design and construction of the nuclear submarine, the Navy chose a conventional foreign submarine project that could transfer the technology to build the hull of a submarine capable of receiving a nuclear reactor, the SN-BR. With the agreement and strategic partnership with France since 2008, this transfer is happening to the non-nuclear area of the SN-BR. In January 2017, the basic SN-BR project was finalized and later certified by French assistance. Currently, the project of the submarine is in the detailing phase.

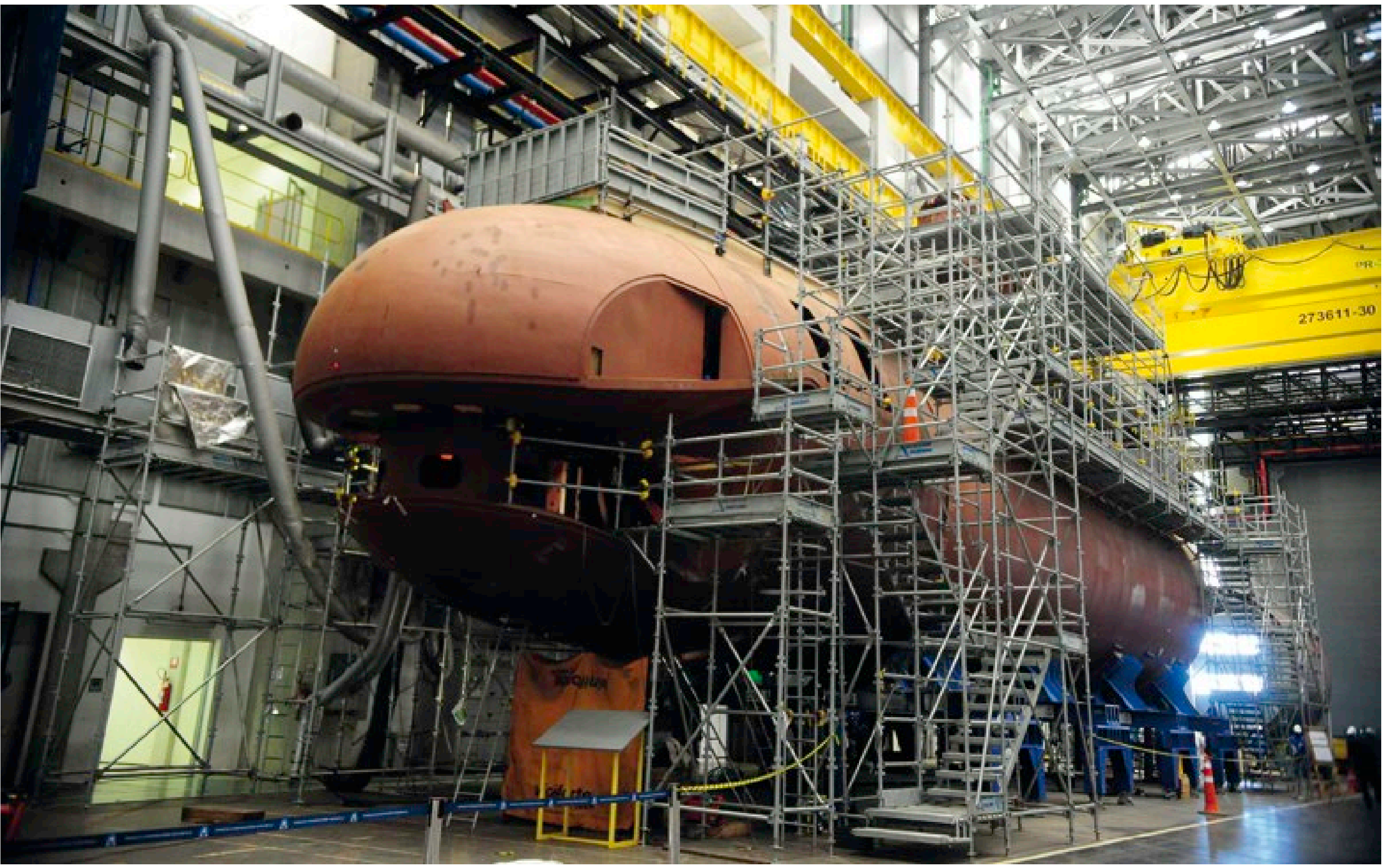
A metal structures manufacturing unit (UFEM) and a construction (ESC) and maintenance (ESM) shipyards were created in Itaguaí in the area of PROSUB. In order to execute the agreements signed with France, the Itaguaí Special Purpose Company for Naval Constructions (ICN), which manages UFEM and ESC, was established. UFEM, a neighbour of NUCLEP (the company in charge of constructing the sections of the submarine hulls), is responsible for completing the submarine hull sections with the most diverse equipment. Its construction began in 2010 and it started operating two years and eight months later. Responsible for integrating the sections, the construction shipyard (ESC) was started in 2009 and began operations in early 2018.

Currently, about 1,150 people work in the ESC. Only six of them are French; the others are Brazilian. The first conventional submarine, Riachuelo, was transferred to the ESC in the beginning of 2018. On February 20,

Figure 2 | Submarine construction | complexity curve



Source: National Shipbuilding Research Program – Advanced Shipbuilding Enterprise. Authors' adaptation.



TÂNIA RÊGO/AGÊNCIA BRASIL

The submarine program has acquired modern shipbuilding technologies and domestic equipment and systems.

the integration of its sections began, a very important milestone for the project.

The training of the Riachuelo crew has already started and the launching of the ship is scheduled for December 14, 2018. In May 2019, the second submarine, Humaitá, will be transferred to the ESC for the integration of its sections. The sections of the third one, Tonelero, and the fourth one, Angostura, are being prepared at UFEM.

The program has adopted modern shipbuilding technologies, as well as domestic equipment and systems, advancing several segments of the domestic industry. Its activities involve 23 universities and research institutions, in addition to nine hundred companies, generating 8,000 direct jobs and 17,000 indirect ones (Figure 3).

Regarding technological benefits provided by PROSUB, several equipment and systems of future use by the Riachuelo class submarines can be mentioned, all of them produced by Brazilian companies:

- navigation, steering, combat system and integrated platform management system consoles (IPMS);

UFEM | MANUFACTURING UNIT OF METAL STRUCTURES, PREPARATION OF THE SECTIONS 2010, 2013 E 2018

FOTOS CEDIDAS PELO AUTOR

SHIPYARD AND NAVAL BASE | INTEGRATION & TESTS 2010, 2017 E 2018

- sonar system cabinets, the main sensor of the submarine;
- thrust bearing (mechanical interface that transmits the propulsion effort from the engine to the hull);
- main switchboard;
- mechanical components (hull valves and actuators);
- various electrical and electromechanical components (pumps, electric motors, converters, cables and batteries).

Benefits can go beyond those mentioned, since the domestic content limit has not yet been reached. There are other project proposals in the same situation. The criteria, requirements and qualification required are within the reach of the Brazilian industry, with cases of export of material for other applications in the French partner company in the program. Finally, the nationalization achieved by Brazil in the construction of the conventional submarine will benefit SN-BR.

The Navy Nuclear Program

The Navy's interest for the nuclear sector was aroused by the involvement of Admiral Álvaro Alberto with the generation of energy from the fission of heavy nuclei, a process he had followed up since it was introduced in the 1940s.

A chemical engineer and explosives expert, an area where he made interesting discoveries, he was a Naval School teacher for several years. There he presented the challenges of the nuclear segment to the students and deepened the subject, until becoming a Brazilian representative and president of the newly created United Nations Atomic Energy Commission (UNECE) for two periods from 1946 to 1948.

Convinced that Brazil would have to develop capabilities to reap the benefits of the newly arising nuclear technologies, Admiral Álvaro Alberto proposed the creation of the National Council of Research (*CNPq*) – currently the National Council of Scientific and Technological Development – to the National Congress through the Brazilian Academy of Sciences (*ABC*) in 1946. The CNPq was founded in 1951, training and supporting researchers from the most diverse areas ever since. Álvaro Alberto was its first president, from 1951 to 1955.

His prestige among scientists led him to preside ABC in the 1935-1937 and 1949-1951 biennia and to contribute decisively to the creation of the National Commission of Nuclear Energy (*CNEN*) in 1956. It is by no coincidence that CNPq has named the nation's highest science prize after him, recognizing the outstanding and pioneering role he has played.

In 1954, Admiral Álvaro Alberto brought in the first three ultracentrifuges for isotopic separation of uranium, precursors of the modern ultracentrifuges developed and used by the Navy and the Brazilian Nuclear Industries (*INB*) in the uranium enrichment process. Years later in 1979, the Navy started a re-equipment program that included procuring a nuclear-powered submarine, which led it to engage in a project to dominate the nuclear fuel cycle and another one to build a nuclear reactor.

The Navy's Nuclear Program has provided access to previously inaccessible strategic technologies and created partnerships with universities and companies.

Figure 3 | Riachuelo submarine's parts being integrated in ESC | Photo dated June 2018

In 1981, a partnership with the Nuclear and Energy Research Institute (*IPEN*), currently a CNEN institute, located on the USP campus, led to the creation of the aforementioned CTMSP, thereby creating a lasting collaboration between these institutions. As a result, it was possible to design and construct a zero-power research reactor completed in 1988, a year in which the country mastered the nuclear fuel cycle, which was extremely necessary to support the various technologies that compose the Brazilian Nuclear Program.

To complete the cycle, it was necessary to master the technology of obtaining uranium hexafluoride and to enrich the isotopic uranium on laboratory scale with centrifuges built entirely in Brazil. While uranium prospecting and mining are under the responsibility of the Brazilian Nuclear Industries (*INB*), the Navy is responsible for converting processed uranium into uranium hexafluoride gas, which is enriched by ultracentrifugation and converted into fuel pellets (Figure 4).

The ultracentrifugation enrichment technology, combined with magnetic levitation, provided the construction of the seven cascades of ultracentrifuges of INB. An eighth cascade is about to start operations and two other ones will be delivered by 2021. Thirty other cascades are planned to be delivered by 2030. They will allow for supplying fuel for our nuclear power plants – currently only partially supplied – as well as for exporting fuel.

As part of the Navy's Nuclear Program, CTMSP is building onshore the prototype of a reactor and a naval propulsion plant at the Nuclear-Electric Power Generation Laboratory (*LABGENE*)[4], a crucial development for the SN-BR, since the transfer of hull construction technology did not include the nuclear propulsion plant. It will be the first power reactor in the country, a pressurized water reactor (PWR), which will be able to be adapted for dual use, in a modular way, providing energy and water via desalination to remote areas where there is shortage.

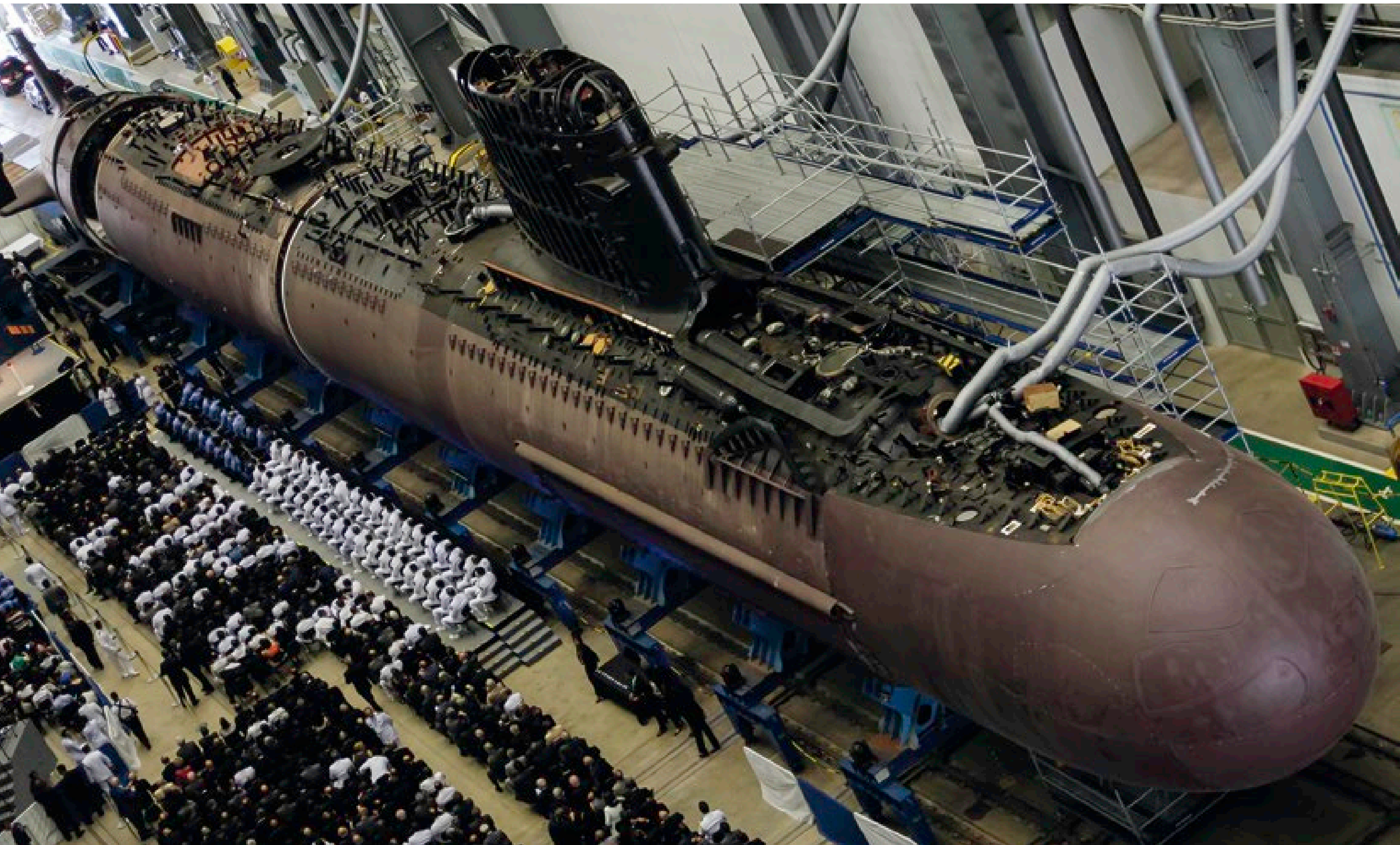
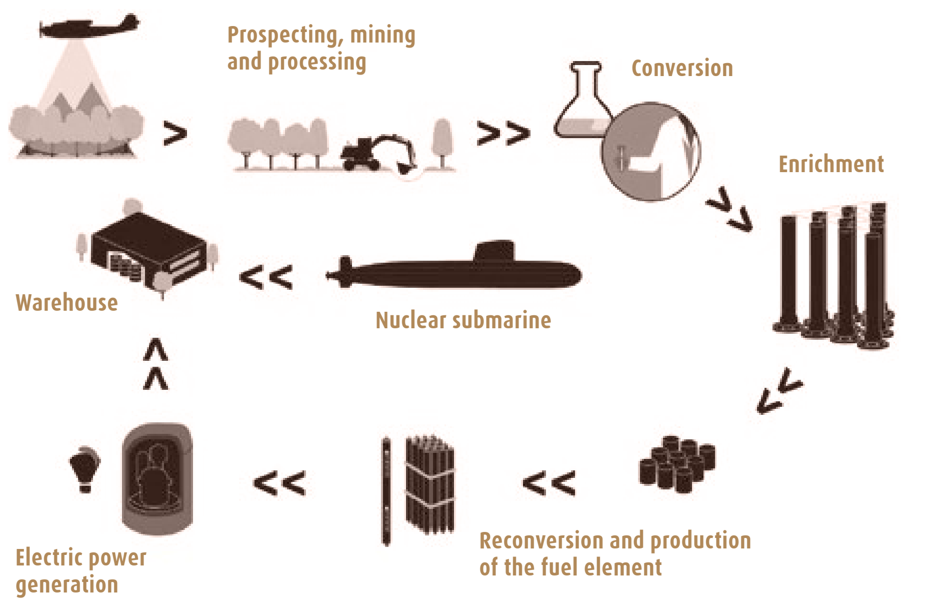


Figure 4 | Complete Fuel Cycle



The Brazilian Navy also collaborates with CNEN, through IPEN, in the project of the Brazilian Multipurpose Reactor (*RMB*), designed to produce radioisotopes and radiopharmaceuticals to irradiate and test materials. This project is of great interest to the Brazilian society, as it will meet the needs of radiopharmaceuticals used for diagnosis and treatment in nuclear medicine. In addition, it will provide neutron radiation beams for research, development and testing of materials.

Final considerations

The mentioned examples highlight the commitment of the Brazilian Navy to the use of science, technology and innovation in the improvement of its capacity to act in the defence of the country. Such a commitment provides additional benefits for the Brazilian society, as we have seen, since it can lead to dual technologies with a wide range of application.

In several projects aimed at training, materials and equipment of interest to the Navy, the importance of the interaction with universities, research centres and technological institutes, as well as association with corporations, is highlighted. Programs such as PROSUB and PNM use the country's existing scientific-technological base. On the other hand, the demands of such programs lead the scientific community to overcome new challenges, thereby contributing to the advancement of ST&I in Brazil and its greater dissemination to society at large.

Conducted with great transparency under national and international safeguards, the Navy's Nuclear Program is a great example of a national strategic program that seeks to provide Brazil with a submarine with nuclear propulsion. It has led us to master the nuclear fuel cycle; to develop previously inaccessible technologies; to create the conditions for constructing the first modular power reactor through pressurized water with possible dual applications; and to collaborate with other strategic initiatives in the nuclear sector, such as the Brazilian Multipurpose Reactor.

As we have seen, the absorption of technology provided by PROSUB has allowed partnerships with dozens of universities and hundreds of companies, generating jobs that contribute to the economic dynamism in the regions around CINA in Iperó and EBN in Itaguaí. This absorption process allows new developments and opens the prospect of partnering with other naval construction projects that will use the complex, modern and sophisticated infrastructure that has been created.

The science, technology, innovation and scientific-technological capacity of our Navy and our people are precious assets for sovereignty and security, essential to the well-being of the population, Brazil's progress and the guarantee of a promising future for the generations to come. ■

Notes

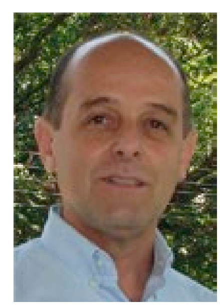
1. Estratégia de Ciência, Tecnologia e Inovação da Marinha – EMA 415
2. Estratégia Nacional de Defesa (END) – Versão 2016.
3. Model created in 1990 by Professors Henry Etzkowitz and Loet Leydesdorff.
4. Concept determined by the United States Department of Defense, which establishes an increasing scale of technological readiness from 1 to 9.

VALDENIO VIEIRA/PRL

THE BRAZILIAN AIRCRAFT CLUSTER
and the innovation system of São José dos Campos

The construction of an aircraft industry is a long-term project that requires the participation of governments, private companies and academic centres of excellence. Since the 1940s, training and research institutions linked to the Brazilian Air Force have formed generations of specialists who have designed and produced state-of-the-art technology that enhances the country's export agenda. Embraer produces sustainable trade surpluses, employs around 17,000 Brazilians and generates orders for one hundred other companies with a high density of skilled labour that operate around it. The region of São José dos Campos (SP) is world famous for the importance of the aerospace industry.

Thiago Caliari
Technological Institute of Aeronautics (ITA).



José Henrique de Sousa Damiani
Technological Institute of Aeronautics (ITA).

With Embraer as an emblem, the Brazilian aircraft industry is often referred to as a success story of industrial policy. The importance that companies, research and teaching institutions and other entities – both public and private and civil and military – had in this success are reflected in the establishment of an important production hub in São José dos Campos (SP) and in its impact on the regional innovation system (IS), which is considered an example throughout Brazil.

This productive, scientific and technological cluster started at the beginning of the 20th century with isolated and poorly coordinated initiatives that had instable public funding. It was clearly redirected in the 1940s, when the aeronautical science and technology (S&T) facilities were established. Since then, a series of events strengthened sectorial and regional capacities, establishing the current base.

This article presents a systematic analysis of these capacities through historical observation, considering the current structure when focusing on the agents of the innovation system and its interactions. In addition, we will observe other aircraft clusters around the world that can be compared with that of São José dos Campos. Initially presenting a conceptualization of innovation systems, the analytical importance of sectorial clusters becomes clear, showing how they have close links with the regional capacity of innovation systems. Then, we present the historical evolution of the Brazilian aviation cluster to the present day, including comments on international cases. In conclusion, the article points out the potential and challenges of sectorial and regional development that must be faced.

Innovation Systems

As the process of technological innovation contributes to the construction of a strategy of economic development and social prosperity, the effectiveness of the virtuous economic cycle is amplified by the greater articulation and integration of the individuals, organizations and sectors which take part in it – especially from academia, government, and private enterprise. It is in this context that productive, collaborative, innovation clusters or innovation systems are arranged, as described below.

Innovation systems engage academia, government and private enterprise in cooperative and competitive relationships – the so-called *coopetition* – within defined geographical spaces in certain economic segments and in specific areas of scientific and technological knowledge and their respective applications (Freeman, 1992; Malerba, 2002). In general, the geographical delimitation of an innovation system (Cooke, 2001; Florida, 1995) provides benefits in the form of *agglomeration economies*, as foreseen by Alfred Marshall. They derive from the joint operation of central companies in a specific industry or sector, and from the operation of their upstream and downstream vertical value chains that are related to and integrated with these central companies.

In this context, there are also organizations supporting central enterprises and their value chains (i.e. public and private institutions for teaching, research and development, innovation and finance) and institutions focused on collaboration and on addressing economic and social challenges (i.e. government agencies, competitiveness centres, technology hubs, incubators, consortia, and trade and industrial professional associations, among others) to promote collaboration and stakeholder interests.

Innovation systems are also related to horizontal and/or vertical industrial chains, together with other segments of competence and economic activity, with which a given cluster maintains interfaces. Producers of new materials, for example, can supply them to both aviation and automotive innovation clusters. This is precisely the example of the positive externalities existing in the innovation system of São José dos Campos, which was drafted with the central participation of the aeronautical and aerospace sectors. In the course of this article, we will highlight the aircraft sector and its importance for the region.

RAFAEL LUIZ CANOSSA/CREATIVE COMMONS

The evolution of the São José dos Campos innovation system and the impact of the Brazilian aircraft cluster

Establishing an innovation system in São José dos Campos is intimately connected with the evolution and consolidation of the Brazilian aircraft industry. It is important to understand the history of this science, technology and innovation complex, as well as the development of the agents within this ecosystem. We highlight the timeline of the aircraft industry in Brazil, observing three periods:

The pre-initial phase

This phase occurred in the period between the 1930s and the creation of the Space Technology Centre (*CTA*) and the Aeronautical Technological Institute (*ITA*) in the second half of the 1940s. It was marked by visionary entrepreneurial initiatives, such as the first plane produced on an industrial scale (Muniz M-7), made by the National Air Navigation Company (*CNNA*) in 1936. Henrique Lage, owner of CNNA, had been trying to develop a domestic plane since 1921, but his efforts were only successful in the government of Getúlio Vargas, after the creation of the Civil Aviation Department (*DAC*) and the Technology Research Institute (*IPT*) of the State of São Paulo. This movement was guaranteed by government demand (airplanes were purchased by the Ministry of War for military and naval reasons) and scientific and technological support for the development of the Muniz M-7. Furthermore, the development of the HL-1 and HL-6 aircrafts, built by CNNA, also had the demand of the Ministry of Aeronautics (Bertazzo, 2003), as later would happen with the Bandeirante and Embraer aircraft.

At the same time, the other private initiatives sought to develop domestic technology. There were emblematic cases such as the Paulistinha CAP-4 and Planalto CAP-1, produced by the Paulista Aeronautical Company of the Pignatari Group, which also had the IPT-USP participation in the development of various aeronautic parts. Moreover, the government sought the consolidation of domestic production and technology by creating the Study Committee for the Instal-

They are great barriers of entry for new players in the aircraft industry. Few countries have managed to take part in this select club where remaining a member is a permanent challenge.

ALDO BIDINI/CREATIVE COMMONS

lation of an Aircraft Factory (*Ceifa*) in 1932.

The beginning of World War II hampered the alliance that was being formed with Germany (Focke-Wulf 44 training aircraft and Focke-Wulf 58 bombers would be produced), to use the Galeão Factory for the production of the Fairchild M-62A Cornell (220 units were manufactured between 1942 and 1952) (Bertazzo, 2003). The IPT-USP also participated in this case, developing domestic components that were inserted in the aircraft over time.

In 1936, the Brazilian Army moved to establish the National Engine Factory (*FNM*), benefiting from a loan from the United States government and an international agreement with the Wright Aeronautical Company. Unfortunately, the delay in production (which only began in 1946) and its high implementation costs led the enterprise to failure, and it was transformed into a truck factory (Bertazzo, 2003).

In addition to the production initiatives, the federal government's strategy in training human resources consisted in periodically sending Brazilian engineers to courses abroad and inviting foreign teachers to give courses in Brazil. These initiatives, however, did not constitute a State policy. They were commonly linked to luck and the political motivation of the ruling government. With the change of government in 1945, a more liberal economic policy was put into practice by General Eurico Gaspar Dutra. The plans to develop a domestic industry were abandoned.

These experiments were based on good intentions, although not sufficiently coordinated to establish relationships among important agents of an innovation system. Most of the time, companies established strategies for productive verticalization, but the complexity of the aeronautical systems imposed technical and economic constraints on project continuity. Most of the Brazilian projects were related to the licensing of foreign technologies or the adaptation of projects, besides being designed by foreign engineers. The IPT-USP was the only important case of the association between science and technology with its simple experimental aircraft (Sarti and Ferreira, 2012)[1]. These problems, in addition to the business strategy mistake (operations in the same market niche or in segments with low domestic demand and low technological capacity) are highlighted as gross failures by Silva (2008).

Furthermore, access to aviation war surpluses allowed American airplanes to enter the market at reduced prices, impacting the efforts to develop domestic companies.

The catching up phase

The creation of the Brazilian Air Force (*FAB*) in 1941 and the establishment of the CTA six years later, thereby defining the Institute of Research and Development (*IPD*) and an engineering training school (*ITA*), were the starting point of this phase, marked by the implementation of the Smith Plan,[2] modelled after the Massachusetts Institute of Technology (MIT), which established the design of the CTA and its institutes. ITA became a benchmark in engineering education, including aeronautics. It was also the source of several national private companies created in the following decades by its alumni, such as Embraer, Avibras, Esca, Tecnasa and Mectron, among others, besides being the main supplier of skilled labour for the IPD (Bernardes, 2000, with authors' additions). The success of this scientific and technological base was followed by the establishment of an institution for certification and promotion of the aeronautical industry: the Institute of Promotion and Industrial Coordination (IFI)[3]. It was also within the scope of the CTA, which soon became an entity of support to the development of the production base for the aircraft industry. With the increased capacity of the IPD, it became necessary to create specializations in research and development. It was separated from the Institute for Space Activities (*IAE*) in 1971 and the Institute for Advanced Studies (*IEAv*) in 1982, followed by the creation of the Advanced Studies Laboratory (*LEA*).

In the late 1960s, the CTA/IPD was the starting point for the development of the EMB-110 Bandeirante and the creation of Embraer. The institution was the provider of technical training and human resources for the company in the 1970s. The creation of Embraer, a state-owned company, faced the challenges and risks inherent in the production of highly complex technological as-

Federal funding agencies like BNDES and Finep contributed about 80% of the resources for research and development. Without them, the Brazilian aircraft industry would not even exist.

sets in an emerging environment that had faced serious business and technological problems in a recent past (Cabral, 1987; Ferreira *et al.*, 2009; Francelino, 2016).

This national technical and managerial capacity is a determining factor in the company's success, but it is also important to highlight the relevance of having established the regional market niche as a business strategy. This is important because it involves reducing barriers-of-entry into production, the access to a market that did not have clear competitors, and the match with government demand that is crucial as the first impetus for production. The government ordered the first EMB-110s and the Ipanema aircraft to the Ministry of Agriculture and obtained the licensing of the production of the MB-326G from the Italian company Aermacchi (known as AT-26 Xavante).

During this period, the establishment of technological partnerships with Embraer's military developments (AT-26 Xavante and AMX) was also fundamental to improving the industrial processes for commercial airplanes, due to the duality of technology shipped in these types of products (Cabral, 1987; Francelino, 2016). For the AMX, the Complementary Industrialization Program (*PIC*) was created in order to qualify Brazilian companies to produce certain strategic items, considering technical training, machine and equipment acquisition, testing equipment, laboratories, services and technological assistance[4] (Francelino, 2016, p. 156/158) with an expenditure of around US$ 600m, as measured by Ferreira (2009) in 2009. However, Silva (2008) harshly criticizes the program, saying that opting for technology imports would have been a mistake, since such a transfer to the limited Brazilian market in terms of size and income was not a recognized strategy according to the transnational corporations. This criticism remits to Ozires Silva's own experience in the development of Embraer, which was developed by acquiring its own productive capacities and technological know-how (Dagnino, 1993). Despite the criticism, it is important to highlight that the PIC provided training for several Brazilian companies, which became major players in the aeronautical sector, such as Aeromot in Porto Alegre. Moreover, Francelino (2016) points out the benefits of the program, including the improvement in the certification capabilities for aeronautical products of greater technological complexity.

During the period, the federal government's efforts to provide the necessary guarantees for sectorial financing were also well known, mainly through the National Bank for Economic and Social Development (*BNDES*), the Financier of Studies and Projects (*Finep*) and other research and development agencies (Ferreira, 2009). The EMB-312 Tucano project, the first civilian purchases for the Bandeirante EMB-110, finance of foreign private entities to purchase aircraft and aid in international certification were often funded by state agencies and banks. Until the 1980s, the public sector was the main source of resources for research and development for the industry, something around 80%, as shown by Bernardes (2000).

The same author highlights the importance of these actions for the creation of the technological infrastructure of in region of São José dos Campos, as well as for generating economies of learning and productive and technological externalities, turning the region into an important hub in the 1970s and 1980s. In addition, the action of the State was essential to establish the bases of the sector and, consequently, of the region. As Pietrobelli and Rabelotti (2009) point out: "Developing countries need to build the initial base of their capacities, supporting their learning processes; their markets and supporting institutions are less developed and therefore less responsive to business needs; clusters and information networks are weaker; the macroeconomic scenario for industrial and technological activity is less favourable; the entrepreneurial ability to withstand the technological risk may also be less developed; and the financial system's conditions are less likely to support such an effort" (Pietrobelli; Rabellotti, 2009, p. 217).

The post-privatization phase to the present

The privatization of Embraer in 1994 marks the third phase of the national aircraft industry. The change of ownership was related to limitations in the state governance structure, restrictions in the federal budget and the end of the life cycle for the company's main products. The creation of financial and technological incentives for this process marked the initial stage with the development of the first regional aircraft project of the ERJ family (ERJ-145). The new controlling shareholder, the Bozzano-Simonsen Group, provided funds to complete the development of this aircraft, which had been started prior to privatization. To deal with internal financial difficulties, Embraer started a kind of relationship with suppliers – the strategic partnerships – which later became a standard in the global aviation industry.

It is worth highlighting the global character of the aircraft industry, which involves complex arrangements of productive, technological and commercial activities. Typically, the leading companies (those integrating projects and assembling the final product) benefit from the productive, technological and scientific hubs around the world, exploiting economies of their partner companies in a well-connected global value chain (Bernardes, 2000; Sturgeon *et al.*, 2013). In this context, Embraer's main suppliers were already foreign companies. By establishing strategic partnerships, this pattern was maintained. This type of partnership was a success and continued to be used for subsequent models of the ERJ family.[5]

The E-Jet family raised Embraer to a level of significant international competition. Today, it is the leading regional jet airline in the world and has been supplying the market with the

The aerospace complex includes the development of complementary technologies, such as radars and flight protection systems, which are essential for air traffic control and defence.

PABLO ANDRÉS ORTEGA CHÁVEZ/CREATIVE COMMONS

second generation of the family: the E2 (EMB-175-E2, EMB-190-E2 and EMB-195-E2) (Vinholes, 2017).

In addition to the successful engineering and production capacity of the main national company, efforts have been made in the recent years to increase the structure of support to innovation in the region, as shown by the number of agents participating in the innovation system in São José dos Campos. In this municipality, since the implementation of the CTA, the ITA and the IPD, a local innovation system has been established and expanded, based on the tripod represented by activities of teaching, research and development, as well as industrial fostering. The country's goal was to master the full cycle of aeronautical technologies, with emphasis on the training of qualified human resources and the autochthonous development of aeronautical technologies embodied in civil and military products.

Over time, the development of this innovation system has received funding, initiatives, incentives and resources derived from policies, plans and programs of the federal government, the government of the state of São Paulo and the municipality of São José dos Campos.

The basis of this innovation system is anchored on the importance of its main company, Embraer, and in the activities of the Department of Space Science and Technology (DCTA), an entity of the Aeronautic Command and of the National Institute of Space Activities (INPE), created by ITA alumni. Furthermore, the Aerospace and Defence Productive Arrangement is also located in São José dos Campos, consisting of about sixty companies which take part of the supply chain of Embraer.[6]

Together, the CTA's (current DCTA) engagement with teaching, research and development, innovation and industrial development activities, with emphasis on aeronautics, space and defence, has also contributed to the development of complementary technologies necessary for the operation of airways, such as radars and flight protection systems, which are essential for the development and operation of integrated defence systems and air traffic control. It is important to point out that the Air Space Control Institute (*ICEA*) and the education, research and development unit of the Air Space Control Department (*DCEA*), which also belonging to the Aeronautic Command, are all located within the DCTA campus.

DCTA's activities had overflowing effects with the development of technologies applied to other sectors besides aeronautics and space. Among them are technologies that contributed to the implementation and development of the National Alcohol Program in the mid-1970s to replace gasoline with ethanol in automotive vehicles and innovative products for other sectors, such as voting machines.

The municipal high school and college education segments benefited from the presence and performance of DCTA and its institutes, which helped to establish organizations such as the Valeparaibana Teaching Foundation, the Everardo Passos Technical School (*ETEP*) and the School of Industrial Engineering (*EEI*). In addition, the federal and state governments implemented new educational agents, the main universities being *Unesp* (São Paulo government) and *Unifesp* (federal government), as well as Fatec.

Entities aimed at promoting the integration of the aeronautical organizations, such as the Brazilian Aerospace Industry Association (*AIAB*) founded in 1990, have acted as important stakeholders in this sector in different fields and among government and private-sector entities as well. Furthermore, the 2000s saw the Technology Cluster of São José dos Campos and the Centre for Competitiveness and Innovation of the *Cone Leste Paulista* (Cecompi)[7] inaugurated. The municipality also has the Technology Hub of the University of Vale do Paraíba, whose current dean has already been the dean of ITA.

The creation of Cecompi and the Technology Hub of São José dos Campos was a political strategic vision that established the importance of the municipality to deepen its position in the aerospace and defence sectors and to establish and occupy prominent positions in new sectors, such as information and communication technology, energy, biotechnology, health, environment and public safety, among other future-bearing topics.

Both hubs host domestic and foreign companies of the most

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diverse productive segments. The Brazilian aerospace cluster, which is the executing institution of the Aerospace Sector Project of the Brazilian Agency for the Promotion of Exports and Investments (*Apex*) and the Brazilian Agency for Industrial Development (*ABDI*), was formed in 2009, bringing together 94 companies from the aerospace and defence industrial complex (Cecompi, 2017).

The National Civil Aviation Agency (*ANAC*) has a regional unit based in São José dos Campos, which incorporated human resources and the technical collection accumulated by the Institute of Development and Industrial Coordination (*IFI*), Department of Aerospace Science and Technology, related to the civil certification of aeronautical products and services. The certification of military aerospace products continues to be carried out by the IFI.

The São José dos Campos innovation system also concentrates most of the scientific, technological and industrial development activities carried out in the space sector in the country through the São José dos Campos Space Centre. Although it is not in the scope of this article, there are some considerations to be made, since it was constituted with the same base and presents productive and technological symmetries.

It is worth mentioning the creation of the National Institute of Space Research (*INPE*) as a strategic initiative of the federal government from the beginning of the 1960s in order to engage the country in space exploration activities, as had already been done by the central countries, such as the United States, the Soviet Union, France and Germany. Around DCTA and INPE, the Brazilian space industry and its organizations have been developed, such as Visiona, Cenic, Orbital and Equatorial, among others. They participate in the activities of the National Plan of Space Activities, whose execution is coordinated by the Brazilian Space Agency (*AEB*). In this case, unlike the aeronautical centre, there is a process of induction to the development of the space industry, known as forward linkages, in which the industry is progressively expanded, from the institutions responsible for producing the initial stock of knowledge and training. Such institutions, in this case, are the DCTA and Inpe, which transfer intellectual assets to the private sector.[8]

Together with the aeronautical and aerospace hubs, a great number of companies and institutions have also developed in the area of defence, as an overflow from the virtuous cycle. Examples include Embraer itself; Avibrás and its subsidiaries; Engesa[9]; Tecnasa[10]; more recently, companies such as Mectron; and Embraer subsidiaries, such as Embraer Defence and Security, Atech and Bradar. These companies carry out activities foreseen in national planning instruments, gathered mainly in the National Defence Strategy (END).

International cooperation has included joint initiatives with institutions that wish to collaborate with the innovation system of São José dos Campos, with significant participation of DCTA, including ITA and the technology park in the establishment of partnerships.[12]

In conclusion, previous statements attest to the importance of establishing centres linked to DCTA and its institutes to promote productive densification and eco-

A large cargo plane and a new fighter jet represent new technological challenges for Brazil.

nomic development of the region, favouring the installation in the municipality of relevant companies in several technology-based sectors, such as automotive, telecommunications, health, electronic, biotechnology, photography, air conditioning, biotechnology and oil and gas. Since the middle of the 20th century, industrial units of global players such as General Motors, Ericsson, Johnson & Johnson, National Panasonic, Philips[13], Kodak[14], Hitachi, Monsanto, Solectron[15] and Petrobras (through its refinery of Vale do Paraíba) have been established in the city of São José dos Campos.

Recently, new strategies to boost and develop the innovation system of São José dos Campos based on initiatives of the Ministry of Defence should be highlighted. In recent years, the development of the KC-390 cargo aircraft (Ribeiro, 2017) and the offset contract for the Gripen NG fighter (program F-X2) with the Swedish company Saab have been the main programs promoting new technologies and enterprises in the aeronautical sector.[16] The estimated budget for these programs is US$ 4.5bn and US$ 5.4bn, respectively (Ministry of Planning, 2014). Since 2005, a regulation by the Aeronautics Command (DCA-360/1) establishes that any importation of goods or services over US$ 5m must involve some compensation agreement for Brazilian companies, increasing the capacity of the IFI to make agreements that favour the domestic industry (Ministry of Planning, 2014).

In turn, ITA has been implementing an expansion program in recent years, which includes an increase in the number of engineers graduated by the institute. Next to it is the project to establish an innovation centre that will operate on both the DCTA campus and the São José dos Campos Technology Park and a complementary training program in innovation, already in operation.

Other international experiences

The experience around the world has shown that the strategy of productive and innovation clusters in generating technological densities is usual among competing companies of the aeronautical and aerospace industry (Niosi; Zhegu, 2005). A process of movement can recently be observed, transferring productive capacities from developed countries to developing countries (Niosi, Zhegu, 2010). It is important to observe other international experiences, especially in situations comparable to those of the São José dos Campos centre, to clarify questions about the strengths and challenges of the region.

Montreal

The most important company of the Montreal cluster,[17] *Aéro Montréal*, is Bombardier – Embraer's main competitor. It was created in 2006 as a strategic think tank that brings together the leading decision makers in the Quebec aerospace industry, including companies, educational and research institutions, associations and unions.

Aéro Montréal adopted a strategic action plan that includes the creation of working groups dedicated to the following areas: supply chain development, branding and promotion, innovation, human resources, national defence and security, market development and trading. This strategic action focuses on the structural changes of the industry is important to guide the development of the companies that operate in the cluster.

For example, prime contractors seem to be reducing the number of suppliers, preferring to work with a smaller number of intermediate companies that offer integrated solutions and manage subcontractors. As a result, global supply chains favour the emergence and development of integrators capable of designing, manufacturing and assembling complete systems. Suppliers of these chains should refine their operational practices, increase their capacity for innovation and promote partnerships in order to work together, becoming more competitive and reinforcing their positions in the chains.

In addition, Aéro Montréal established a Value Chain Development Working Group, composed of thirteen representatives of its companies, with the purpose of supervising the planning, coordination and implementation of an action plan to respond to the main challenges of subcontracting, to increase the competitiveness of the suppliers of the Québec aerospace cluster and to strengthen it in the face of the international competition.

In general, Aéro Montréal promotes the growth of the Canadian aerospace cluster through the strengthening of synergies, seeking to maintain the position it has achieved in the world. It acts to strengthen and consolidate its strategic positioning, promoting the development of markets for its companies. In this sense, emerging and niche markets represent opportunities for the aerospace sector, as well as those resulting from the use of drones and MRO activities (Maintenance, Repair, and Operations).

Aerospace Valley (France) and Netherlands Aerospace Group (The Netherlands)

Aerospace Valley[18] supports companies that compete with the innovation system of São José dos Campos, such as Airbus, which recently incorporated Bombardier's regional aircraft division (which in turn is supported by Aéro Montréal).

Created in 2005, the Aerospace Valley is considered the most important centre of competitiveness and innovation in France in the aeronautics, space and embedded systems sectors. It has more than 840 members, both from industry and academia. It has offices in Toulouse and Bordeaux, and its innovation cluster covers two adjacent geographic regions of the French southwest, Occitanie and Nouvelle-Aquitaine. The cluster provides 124,000 industrial jobs, which corresponds to 1/3 of the French labour force in the aerospace sector. It also brings together 8,500 researchers and scientists, representing 45% of France's potential in aerospace research and development. Aerospace Valley obtained financing of 475 projects, totalling €1.2bn (June 2016 data). The French cluster intends to create between 35,000 and 40,000 new jobs by 2025 under the French program for centres of competitiveness.

The Netherlands Aerospace Group (NAG) is concerned with the continuous preparation of its members for international competition by supporting actions for knowledge exchange; defending the interests of the sector and access to domestic and international markets, as well as organizations of the group. NAG brings together around 100 organizations, representing approximately 95% of revenues in the Dutch aerospace industry. NAG members are at the frontier of knowledge in areas such as new materials, production technologies, airport maintenance and development. NAG has representation in Brazil. It is important to note that the Dutch aeronautical industry has a consolidated annual revenue of €5.5bn, occupying the sixth position in Europe and employing around 20,200 people. The industry invests around 8% of annual research and development revenue, distributed among more than 100 companies and research institutions, such as the Delft University of Technology, the University of Twente and the Dutch Aerospace Laboratories (NLR).[19] Embraer Netherlands is part of NAG.[20]

Mexico

The Monterrey Aerocluster was created in 2009, according to the triple helix model, involving six companies, two universities and two government entities. The aerospace cluster of the state of Nuevo Léon aims to promote regional integration for the development of the aerospace sector. Its work is focused on incorporating local companies into domestic and international value chains, through the development of projects that foster synergies among local agents.[21] The activities of the cluster are supported by specialized facilities, such as the Centre for Innovation in Aeronautical Engineering (*CIIA*), the Open University of Nuevo Leon (*UANL*) and the Monterrey Technology Park, which, just like the university, plays an important role in areas such as new materials and nanotechnology. The CIIA is associated to the Mechanical and Aeronautical Engineering University (*FIME*) of UANL.

In Mexico there is also Aerospace Querétaro, an agent for change that facilitates and expands the opportunities to develop the aerospace industry at the state, national and international levels. The cluster coordinates the activities of companies, research centres, educational institutions and government organizations, as well as the development and integration of small, medium and large companies in the aerospace value chain. It also implements innovative plans and programs to establish strategic alliances among the players in the aerospace value chain.[22]

Mexico is considered a strategic region for the manufacture of aeronautical components, with a growth rate of 15% a year during the last three years. The country has demonstrated great ability to attract foreign investment through new research, development and innovation projects. The Mexican aeronautical industry is oriented to design, manufacture, maintenance and training services. The states of Baja California, Nuevo Leon, Queretaro, Chihuahua, and Sonora house most of the aeronautical companies in the country with about 45,000 professionals.

The program also includes governmental, industrial and academic engagement in the development of strategic sectors not yet installed in the country, such as propulsion systems, flight control and avionics – areas in which Brazil also has deficiencies in its aeronautical production chain.[23] Organizations of great relevance to the pursuit of these objectives are the Centre for Industrial Engineering and Development (CIDESI) and the Centre for Aeronautical Technologies (CENTA) in the city of Santiago de Querétaro. It should be noted that CENTA has been carrying out the design of an aircraft entirely developed by Mexican specialists. The organization seeks to play a similar role to that of DCTA in the promotion of the Brazilian aeronautical industry.

United States

Due importance should be given to the Washington state-based aerospace cluster,[24] particularly when considering the ongoing partnership between Embraer and Boeing. This cluster was the first to be established in the aerospace industry and is the largest of them. It began in 1916 with a single humble red barn in Seattle. Today, it employs more than 132,000 people in more than 1,350 enterprises. Washington's aviation industry generated US$ 76bn in economic activity in 2012, paying a total of US$ 11.5bn in wages, representing 11 percent of total wages paid in the region.

In Washington state, about 175 companies work directly in the aerospace industry, generating 94,200 jobs in 2012. Companies directly related to the sector generated 38,300 additional jobs, in a total of 1,350 firms.[25]

Companies in the Washington state aerospace cluster have links with the global supply chain of aeronautical manufacturers, including Airbus, Bombardier, Comac, Mitsubishi Aircraft Company and Embraer. Among US companies supplying parts to Airbus, Boeing's European competitor, Washington is only less important than California.

It complies with the need to increasingly compete for new business due to the worldwide growth of aerospace clusters. Aeronautical manufacturers rely on a growing number of alternative locations to assemble their aircraft. However, a relevant attribute for attracting new business is access to human resources and specialized facilities. The University of Washington (Seattle) has become one of the American public universities to play a leading role in supporting the development of new aerospace technologies, while Washington State University (Pullman) is expanding its engineering programs in Everet, taking over the management of the University Centre of North Puget Sound.

Portugal

The Portuguese cluster has about sixty companies, earning €1.87bn in 2017 and represented 1.2% of the country's GDP, employing 18,500 people. About 87% of the production is destined for export. The industry is mainly made up of small businesses. Nine research institutes and four universities graduate approximately 120 space engineers per year.[26]

Although the Portuguese cluster only appeared 2007, it is now comparable in terms of size with the totality of jobs generated in the Brazilian aeronautical industry. It is the result of a recent policy, established in a coordinated manner and directed by the Portuguese government to meet specific targets for the integration of the innovation system. The institution to support the cluster only started operations in 2016.[27] Embraer has two factories and an engineering centre in Portugal, with approximately 450 employees and providing products for the company's three business areas (commercial, executive and defence).

Conclusions and remarks

The activities of the Brazilian aeronautical cluster began in the 1940s. Since then, it has seen its main company become a world leader in the manufacture of aircraft in its segment. Its development is directly linked to the evolution of the relations and institutions of the innovation system of São José dos Campos. Due to its relevance, it is often pointed out in the academic and professional literature as a case-study of the success of industrial policy. It has sustainable commercial surpluses, employs approximately 17,000 people and has approximately 100 companies operating in its environment.

Despite these results, much is still being discussed about the long-term sustainability of Brazilian competitiveness, given the inequality in capabilities of companies operating in this cluster. Despite the success of Embraer, the participation of Brazilian companies that operate with higher added-value is weak; Akaer, associated with SAAB, may become the first such company. The fact that no Brazilian company is a risk partner of Embraer or any global aircraft manufacturer shows that the productive and innovative capacity of the Brazilian industrial complex is concentrated in its leading company and the Department of Aerospace Science and Technology.

Among the challenges of the Brazilian aeronautics industry is the need to constantly improve the companies that constitute its supply chain, besides expanding coverage and depth of its supply chain by integrating with a greater number of companies at its higher levels, closer to their central company, by both promoting local companies to higher value-added positions in the chain and founding new organizations – in the so-called, *densification* of the production chain.

International observation demonstrates that specific strategies led by aggregating agents have been important – regardless of company maturity – including the establishment of representative associations of clusters and well-established strategic planning that is well co-ordinated among players.

This positioning represents significant competitive challenges for the local environment and requires the necessary action to ensure its future expansion and sustainability. Such action may include strategic development plans and programs in order to face competition, including initiatives such as establishing strategic partnerships – or partnerships such as the one underway between Embraer and Boeing. It should be added that this potential partnership may have highly relevant impacts, although difficult to assess and predict in relation to the industry and the local innovation ecosystem. There will likely be profound and relevant implications for the research, development, innovation, and industry architecture established locally over the past seventy years, as well as for its stakeholders. The analysis and decision-making about the final configuration should be the subject of extensive reflection, due to the impacts on the local innovation ecosystem and its contributions to the economic and social development.

Finally, the most recent stimuli for the São José dos Campos innovation system brought challenges related to the continuous promotion of innovation and competitiveness in its traditional segments of activity, through the development and improvement of the structural components, as well as the skills and ability to act in new segments. The implementation of development programs and production of new aircraft, such as the previously mentioned KC-390 and FX-2, and spacecraft, such as launchers and satellites, are expected to bring important contributions to the acquisition and internalization of new technological assets and industrial processes, as well as for the expansion and densification of aeronautical, space and defence value chains. These programs will also contribute to addressing the challenges and international competition in the commercial aviation segments where Embraer holds a leading position.

An example of these challenges is the fact that in November 2015 the Chinese state-owned aircraft manufacturer Commercial Aircraft Corporation of China (Comac) introduced the C919, the largest commercial aircraft ever developed in China, which intends to compete with similar models, namely the Boeing 737-800 and the Airbus A 320.[28] It will also be able to compete with the advanced versions of the new Embraer family of regional jet planes under development.

These challenges must be faced as a combination of relationship strategies between all players of the innovation system in the internationalization of contacts and local capacities. The authors of the present article believe there are important capabilities in the region. In a recent study by *fDi Intelligence*, a specialized international market magazine for The Financial Times newspaper, São José dos Campos was named as the main city in the world in the ranking of strategic potential for foreign direct investment in the aerospace sector.[29] However, the vision and the joint action of the system to achieve sustainable and competitive economic and social development remain relevant factors. ■

Notes

1. As pointed out by Hausmann and Rodrik (2003, p.605), '... even when the production techniques used in the advanced countries are transparent to outsiders, their transfer to new economic and institutional environments typically requires adaptations with uncertain degrees of success'.
2. The Smith Plan, prepared by the then Lieutenant Colonel of the Brazilian Air Force, Casimiro Montenegro Filho, and Professor Richard Harbert Smith of MIT, implemented the model of the Aeronautical Technical Center (CTA) and its initial institutes, the Aeronautical Technological Institute (ITA), and the Research and Development Institute (IPD). The development of the Bandeirante aircraft was carried out in the IPD, through Project IPD-6504, whose initial flight occurred in 1968. The success of the project led to the creation of Embraer, through an initiative of the Ministry of Aeronautics, supported by the Federal Government.
3. The certification of the Bandeirante aircraft by the CTA/IFI was essential for its export and success in the international markets.
4. "During the same period, Embraer also sought to encourage the strengthening of domestic suppliers. For the subcontracting of finished parts, Embraer established the concept of "integrated supplier", considering that it would not be rational to schedule and control eight thousand items in a universe of fifty suppliers. Therefore, it focused on the better equipped suppliers, who for their own benefit took on the task. Initially, twelve small companies were selected, with one-year planning data based on Embraer's sales forecast. This concept worked well until the early 1990s, when the economic crisis interrupted the network of integrated suppliers' (FERREIRA, 2009, p. 173-174).
5. In the ERJ-145 there were four risky partners: Gamesa (Spain), Sonaca (Belgium), C & D (United States) and Enaer (Chile). In the ERJ-170/190 project there were a total of 11 risky partnerships.
6. It is estimated that the Brazilian aeronautics industry, most of which is based in São José dos Campos, has generated cumulative trade surpluses for the country of over thirty billion dollars since its creation, with the implementation of Embraer and its successful access to the international aeronautical industry, showing its potential and the capacity to generate economic value, supported by the production and incorporation of technological innovations, especially enhanced by the Innovation System established in the region.
7. One of the references for the conception of Cecompi was the Council on Competitiveness Center, founded in 1986, which is a non-partisan leadership organization of corporate CEOs, university presidents, labor leaders and national laboratory directors committed to advancing US competitiveness in the global economy and a rising standard of living for all Americans. Source: http://www.compete.org/about, accessed January 13, 2016.
8. This process of forward linkages of the space sector has not presented the same effectiveness of the backward linkages, which have promoted the development of the aeronautical industry and its consolidation. The increase in the performance of the process inducing the expansion of the space industry constitutes a significant challenge for the Municipal Innovation System, given the essentiality of this sector to the economic development and national sovereignty. The creation of Visiona, a joint venture established by Telebrás and Embraer, has a strategic character for the development of the Brazilian space industry and may play a role similar to that carried out by Embraer as the integrating organization of the aeronautical industry and promoter of its development.
9. Engesa, as a result of the unfolding of international war conflicts, closed its operations in São José dos Campos.
10. Tecnasa, as a result of developments in the technological evolution of flight protection systems and embedded systems and telecommunications, ended its activities in São José dos Campos.
11. The National Defense Strategy is focused on medium and long-term strategic actions and aims to modernize the national Defense structure, acting on three structuring axes: reorganization of the Armed Forces, restructuring of the Brazilian defense material industry and policy of composition of the Security Forces. Source: https://www.defesa.gov.br/arquivos/2012/mes07/end.pdf. Accessed on October 2, 2018.
12. One example is the Autonomous University of Nuevo León (UANL), located in Monterrey, Mexico, through its Faculty of Electrical and Mechanical Engineering (FIME) and the Center for Research and Innovation in Aeronautical Engineering (CIIIA), which have been establishing, since 2014, cooperative efforts with ITA, in the area of Aeronautical Engineering. It has also been sought to establish joint activities between the Aerospace and Defense Local Productive Arrangement (APL) with the aeronautical cluster located in Monterrey. Likewise, cooperation activities with the Association of Dutch Aerospace Companies - NAG - have been promoted, both aiming, among other purposes, to promote the internationalization of APL.
13. Kodak, due to the evolution of digital photography and organizational restructuring, ended its operation in São José dos Campos.
14. Philips, as a result of the evolution of image projection technology and organizational restructuring, ended its operations in São José dos Campos.
15. Solectron, a company that manufactures under contract electronic equipment for OEMs in the sector ended its activities in São José dos Campos, as a result of a corporate decision. Its facilities were then acquired by the Municipal Government of São José dos Campos and were destined to the Technological Park of the municipality.
16. Both programs are managed by the Coordinating Commission of the Combat Aircraft Program - COPAC, which is part of the Department of Aerospace Science and Technology (DCTA).
17. Source: https://www.aeromontreal.ca/who-we-are.html, accessed on October 3rd, 2018.
18. Source: http://www.aerospace-valley.com/en, accessed on October 3rd, 2018.
19. Source: https://nag.aero/sector/, accessed on October 4, 2018.

20. Source: https://nag.aero/sector/, accessed on October 4, 2018.
21. Source: http://www.monterreyaerocluster.com/nosotros/, accessed on October 3, 2018.
22. Source: https://aeroclusterqueretaro.mx/about/, accessed on October 3rd, 2018.
23. Source: https://www.cidesi.com/rtna/index.html, accessed on October 3rd, 2018.
24. Source: https://aviationbenefits.org/case-studies/washington-state-the-ultimate-aerospace-cluster/, accessed on October 3, 2018.
25. In December 2013, Boeing employed about 82,000 workers in Washington State. In 2012, the company paid more than US$ 4.6 billion to its 2,042 suppliers. According to the State Department of Commerce, the company's exports accounted for 53% of total exports in 2013, totaling US$ 43.6 billion, an increase of 61% since 2011. Projections show that this performance will grow in the coming years, as the company's production level rises to meet the world demand for air transportation. At the Boeing plant in Renton, production has reached 42 monthly units, a quantity that is expected to rise to 52 units by 2019.
26. https://observador.pt/2018/05/25/setor-aeronautico-em-portugal-quer-atingir-3-do-pib-em-cinco-anos/. Accessed on October 3rd, 2018.
27. Source: http://www.aedportugal.pt/. Accessed on October 4, 2018.
28. The C919 is a narrow-body and twin-engine fuselage jet plane. According to the Chinese manufacturer, the basic version can accommodate 158 passengers divided into two classes or 168 in a single class. Comac also suggests a "high density" configuration with 174 seats. The standard model range is 4,075 km or 5,500 km in the extended range version "C919 All ECO". Source: http://airway.uol.com.br/china-apresenta-jato-comercial-para-brigar-com-airbus-e-boeing/, accessed on November 2nd, 2015.
29. https://www.fdiintelligence.com/Rankings/fDi-s-Aerospace-Cities-of-the-Future-2018-19-FDI-Strategy. Accessed on October 2nd, 2018.

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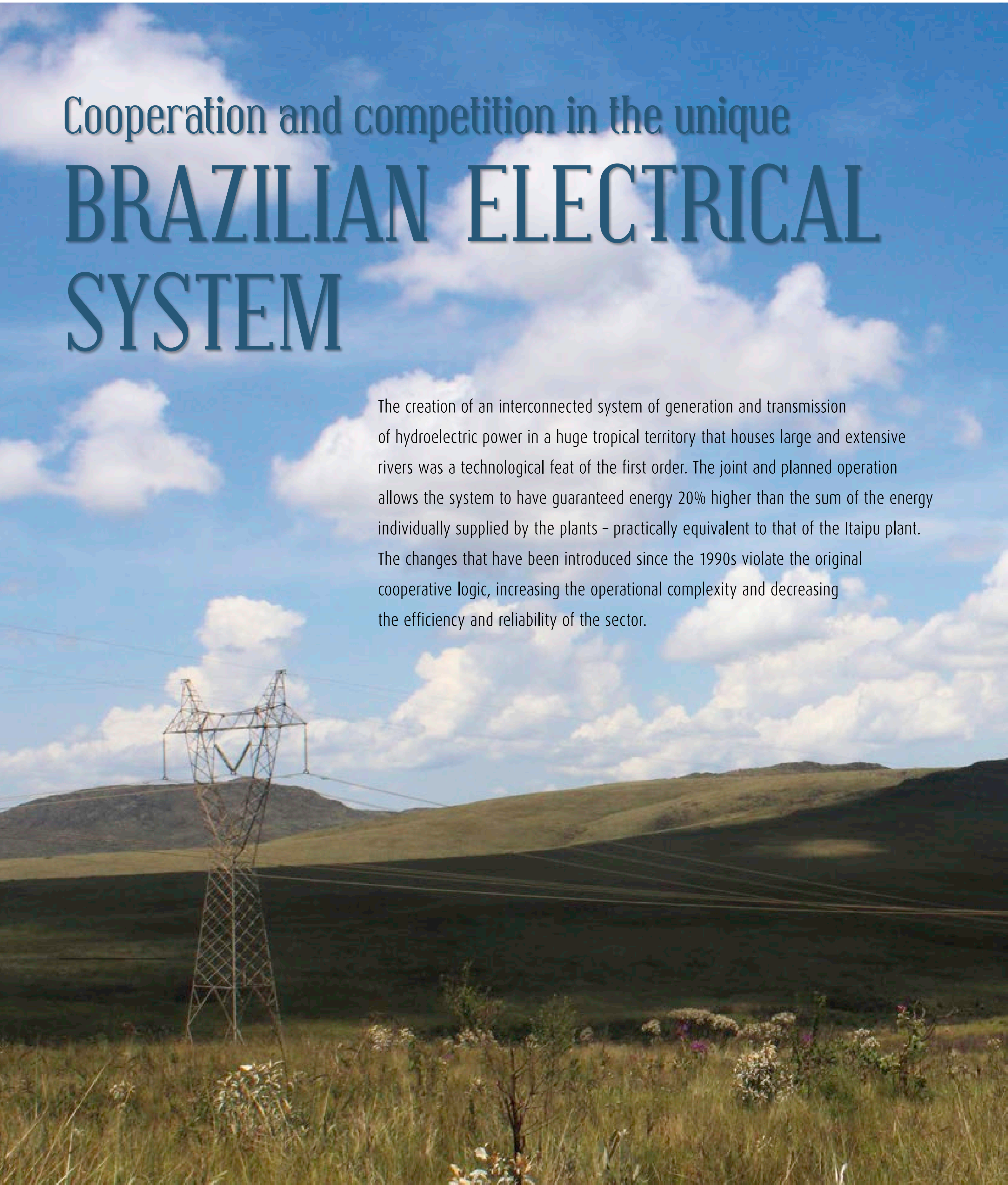
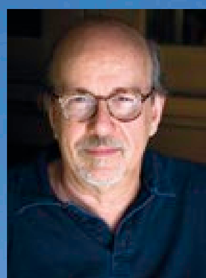
Cooperation and competition in the unique BRAZILIAN ELECTRICAL SYSTEM



The creation of an interconnected system of generation and transmission of hydroelectric power in a huge tropical territory that houses large and extensive rivers was a technological feat of the first order. The joint and planned operation allows the system to have guaranteed energy 20% higher than the sum of the energy individually supplied by the plants – practically equivalent to that of the Itaipu plant. The changes that have been introduced since the 1990s violate the original cooperative logic, increasing the operational complexity and decreasing the efficiency and reliability of the sector.



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Introduction

It is said that the great novelty of the moment in the economy and in society is the increasing connectivity among equipment and people. However, few know that the Brazilian electrical system had already anticipated this concept decades ago, creating a state-of-the-art technology solution adapted to the conditions of the country.

The story begins with the Canambra Project, a consortium formed by two Canadian consulting firms – Montreal Engineering and Crippen Engineering – contracted by the Brazilian government and the World Bank in 1962, when Eletrobrás was founded. The project undertook studies on the hydro-electric and market potential of the Southeast region.This was the beginning of the pioneering work of the integrated planning of our electric sector and the first detailed survey of the Brazilian hydroelectric potential, studying all the regional rivers from their sources to their deltas.

In 1964 a decree established that Eletrobrás would be responsible for monitoring the execution of the proposed projects. With the approval of the final report in 1967, Eletrobras' mission was expanded to the North and Northeast regions, demanding the creation of two other regional subsidiaries.

The study revealed that Brazil had uniquely favourable geography for the exploitation of hydraulic potential. The interlocking of our electrical system, however, had yet to be imagined. In order to understand it, we need to analyse our geography.

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The Brazilian territory

Geographic coordinates are a kind of cartographic representation formed by imaginary lines – latitudes and longitudes – used to represent and locate any point on Earth's surface. Latitude (or "parallel") is the distance in degrees from any point in relation to the Equator.

Considering contiguous territories, Brazil covers 39 degrees from 5°16' latitude at the northernmost point (Mount Roraima National Park) to 33°44' in the extreme south, on the border with Uruguay. Russia is in the second position, with a difference of 36,5°: the northernmost point is at 77°43' and the southernmost at 41°11'. Chile is in the third position, with 36,4° from 17°30' to 53°53'.

We have four types of climate: humid equatorial in the North, tropical in the Southeast and Midwest, semi-arid tropical in the Northeast and humid subtropical in the South. Moreover, we have a large amount of renewable resources, among which stand out about 8,233 km3 of fresh water, 12% of the world's available quantity. The Brazilian Amazon holds more than 70% of this total.

Many rivers flow through long extensions before emptying into the sea: the Paraná river is 3,942km long; the São Francisco, 2,800km long; the Madeira, 3,315km long; the Tocantins, 2,700km long. They are "upland rivers". In this kind of river, the slopes where plants can be constructed lie between two semi-flat surfaces. When damming such a river, large reservoirs are formed.

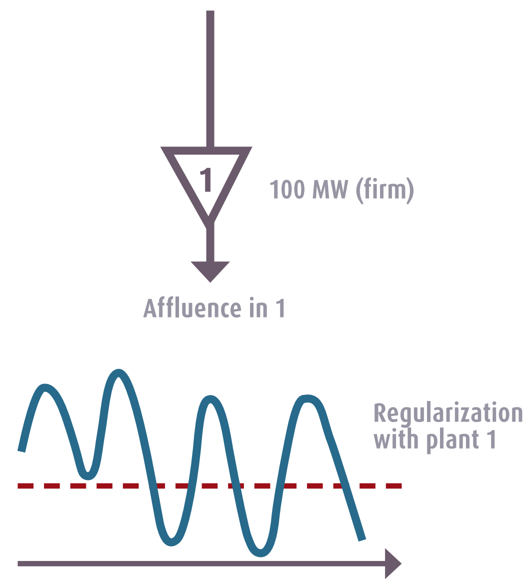
The deployment of an electric sector based on hydro-electric power plants is an old idea. It was boosted by the need to industrialize the country. Large dams impact their respective regions, but they were not created by megalomania or obsession with "pharaonic" works, as is often alleged. They were built due to Brazilian geography.

Our extensive territory is blessed with these characteristics thatoffer great advantages, which we were able to exploit at a certain point in the past. Brazil understood its geographical singularities and built a particular hydroelectric system, endowed with incomparable efficiency.

The best way to understand it is picturing the sector emerging from scratch. Imagine a river where an investor builds plant 1, with guaranteed 100MW (note that 100MW is not the power of the plant, but rather the amount of energy it can supply continuously). Figure 1 shows that the affluence is very variable. However, thanks to the reservoir, the plant can regulate these variations and guarantee an energy equivalent to the dashed line. By storing water, it ensures firm energy. Some of the larger inflows are lost, since the reservoir capacity is not enough to store them until the next dry period.

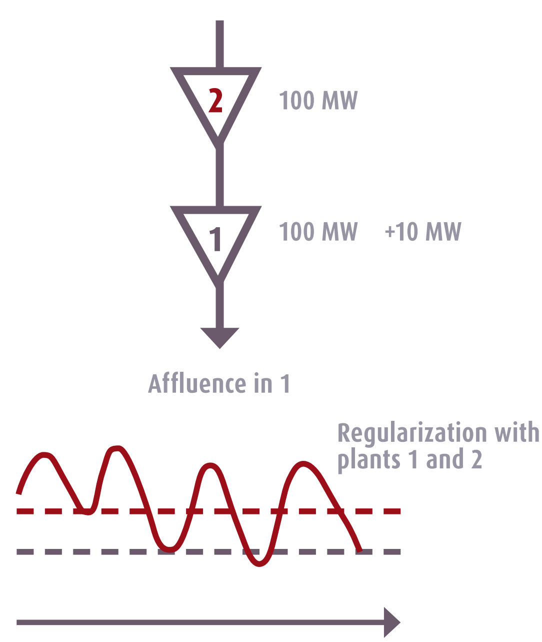
Let's suppose that another investor builds another plant upstream, with the same capacity. As plant 2 also has a reservoir, it

Figure 1 | Situation with a single plant



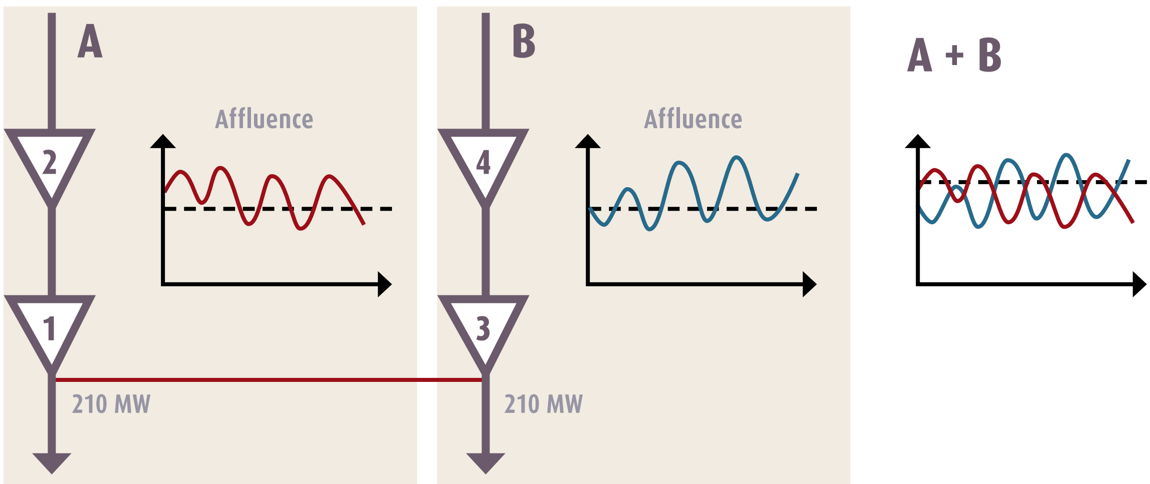
INFLOWS FLUCTUATE (CONTINUOUS CURVE), BUT A RESERVOIR ALLOWS THE PLANT TO GUARANTEE FIRM ENERGY (DASHED LINE).

Figure 2 | Situation with two consecutive plants



A SECOND PLANT DOWNSTREAM FROM THE FIRST ONE, BOTH WITH RESERVOIRS, ALLOWS FOR BETTER REGULARIZATION OF THE RIVER FLOW AND INCREASES THE FIRM ENERGY OF PLANT 1, WITHOUT INSTALLING A NEW TURBINE.

Figure 3 | Role of a transmission line



A TRANSMISSION LINE CONNECTING POWER PLANTS LOCATED IN TWO DIFFERENT RIVERS ALSO INCREASES THE FIRM ENERGY AVAILABLE TO THE SYSTEM.

further regulates the flow of the river, so that the affluence of plant 1 becomes more well-behaved: the droughts are not so intensive (oscillating curve in Figure 2). Thus, the firm energy of plant 1 increases. Now, it produces 110MW of firm energy, with no capacity increase, meaning without new turbines. This is enabled by water management.

A question then arises as to who owns the 10MW of firm energy generated with no addition of new equipment. It may be plant 1, since its machines generate this capacity. It may also be plant 2, since this was the one that altered the behaviour of the perceived affluence in plant 1. Or it may be both, but in what proportion? What criteria should be adopted?

There is no reasonable answer to this problem, since it is impossible to separate functions in a clear and uncontroversial manner. And as hydrology varies over time, so does this effect. Both reservoir 2 and plant 1 are important to guarantee the energy that will be generated.

So far, there are no major differences regarding the electrical systems installed in other countries, except for the combination of fluctuations in flows (larger in tropical regions) and reservoirs. But the game is not over. As in the first river (A), something similar occurs in another one (B). There, plants 3 and 4, similarly to 1 and 2, had the same effect and were associated in exploiting 210MW.

Then another investor analyses the data and decides to build a transmission line that can join the two systems (A and B). River B's hydrology is different from River A's. When River A has lower inflows, River B has higher inflows. As shown in Figure 3, now instead of the sum of the previous firm energy remaining the same, surprisingly, another 20MW of firm energy appears!!

This hydrological diversity is typical of countries of greater latitude. It offers our transmission lines an unprecedented function among electrical systems around the world, since the market is served simultaneously by a great quantity of plants, scattered throughout the national territory.

By allowing large-scale shipments between regions, the transmission system will behave like a "traveling reservoir", as it is able to "relocate" the water supply, avoiding unnecessary spills. If properly dimensioned, the lines are also capable of emptying certain strategically chosen reservoirs, scheduling their waiting volumes and transforming a greater quantity of future rainfall into kWh. The greater the capillarity of the transmission system, the greater the probability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that inflows throughout the system (now A + B + T) can be converted into kWh at any time.

However, the game is still not over: Imagine that another investor decides to build a thermal plant connected to the A + B + T system. With this new plant, the whole system gains more firm energy, even if the new plant does not generate any MWh! Although inactive, it works as a safety guard, allowing the reservoirs to be operated in a more daring way.

As a precaution, A + B cannot drastically reduce the volume of their reservoirs. However, some water is lost in rainy seasons, since it is necessary to let it flow without generating energy due to the lack of space to store it. With the thermal plant that can be triggered in case of need, the A + B + T system can take the risk of pouring more water in the present and opening more space in the reservoirs for a quantity of rain that could not have been previously stored.

This effect occurs in any water-based system, but not in Brazilian proportions. The guaranteed energy of our whole system is 20% greater than the sum of the guaranteed energy of the plants, when analysed separately. That is, the complex of lines that interconnect the system "offers" 20% extra energy in the total guarantee. Currently, this means a quantity of energy equivalent to the production of the Itaipu plant, the largest unit in the American Hemisphere.

This imaginary exercise shows that if the Brazilian system had been developed by individual initiatives, they would have quickly realized the need to associate among themselves. Given the uniqueness of our geography, this association must necessarily include the plants (thermal and hydro) and the lines. We are facing a natural monopoly. To be efficient, the system must be planned and managed as a single company.

The connectivity of the electrical system

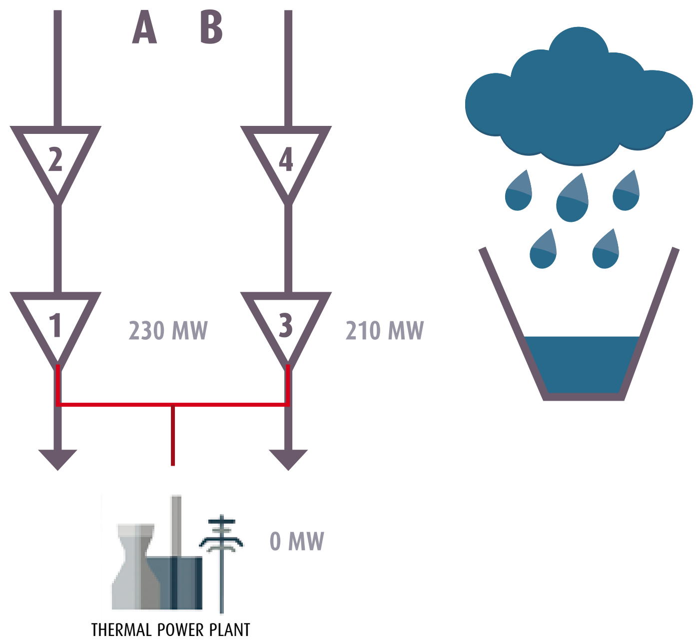
Figures 5 and 6 show the development of the Brazilian electrical connectivity, using 1970 and 2017 as reference.

In order to evaluate the size of our transmission system, we can simply draw it on the map of Europe, as shown in Figure 7: the lines link Portugal to Sweden and almost reach Moscow.

What is the justification for a single system covering a territory equivalent to that of Europe? Can the Brazilian transmission system be considered excessive?

In Brazil, not only where but when one should generate is imposed. Every drop of water held in reserve contains a challenge: when should we use it? This dilemma is non-existent in thermal-based systems.

Figure 4 | Integration of a thermal plant in a hydro system



THE EXISTENCE OF A THERMAL POWER PLANT, ALTHOUGHINACTIVE, INCREASES THE ENERGY OFFERED BY THE SYSTEM, SINCE IT ALLOWS A MORE DARING MANAGEMENT OF THE RESERVOIRS OF THE HYDROPOWER PLANTS.

Figure 5 | The transmission system in the 1970s

Figura 6 | The transmission system in 2017

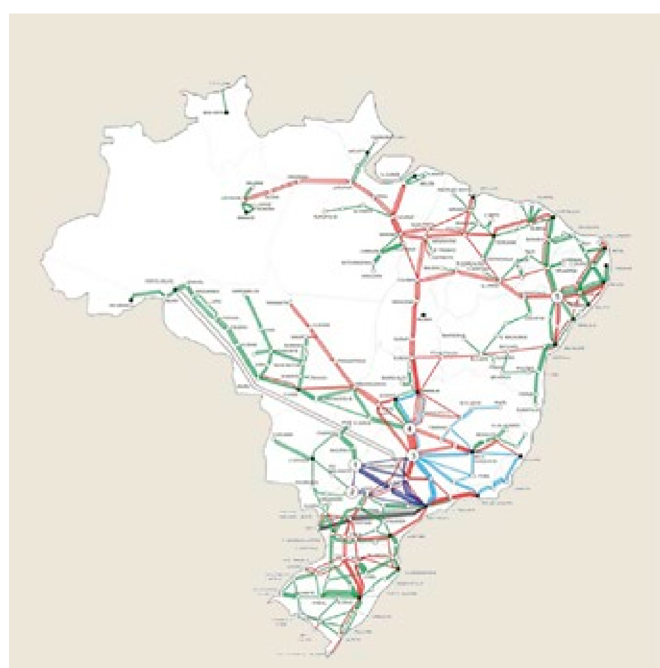


Figure 7 | Brazilian transmission system drawn on the map of Europe

Figure 8 represents the amount of energy exchanged between the Southeast and South regions. The positive values represent the energy sent by the plants from the Southeast region to the South, and the negative values represent the exchange in the opposite direction. As it can be seen, it is common for this exchange to exceed 2,000MW on average.

Let's see what that means. The Itumbiara plant, located on the Paranaíba River, with 2,082MW installed, has firm energy of approximately 1,000MW on average. Exchanging 2,000MW on average is equivalent to "transporting" two plants like Itumbiara through the lines. To emphasize this unique situation of the Brazilian system, it is enough to realize that, for some months, more than 50% of the consumption of the South region is served by plants from the Southeast.

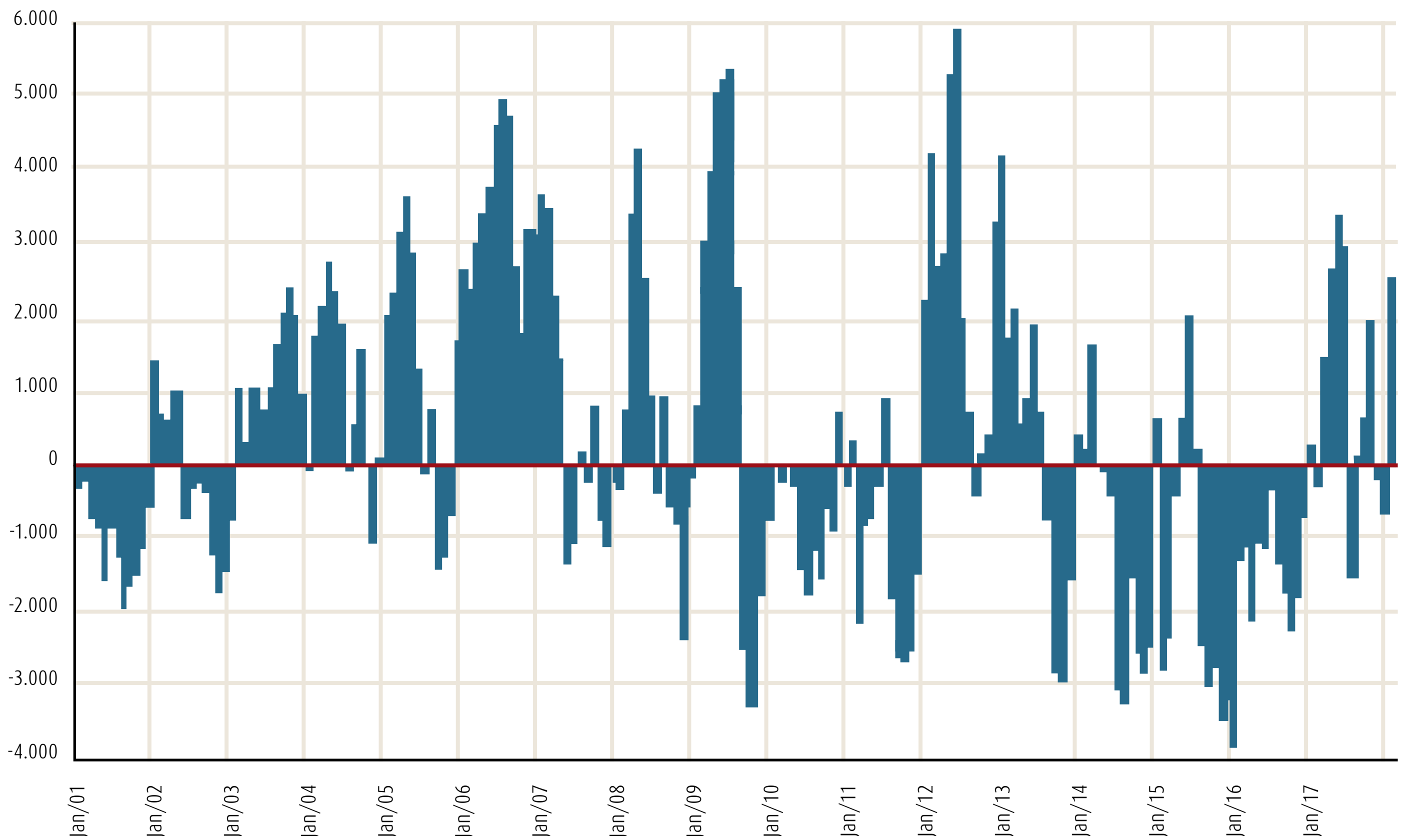
There is great variation in the production of each plant, which depends on both the regional hydrology and the interregional logic of the interconnected system. Therefore, the Brazilian system can only be correctly managed from an overall view. It was managed by the operation and planning committees, coordinated by Eletrobras. There were always several distribution and generation companies, but the planning of the operation and expansion was intensely debated in these committees, with the decisions being submitted to criticisms and approvals. They did not depend only upon the hydrological diversity resulting from geography.

As already mentioned, our upland rivers were favourable to the construction of large reservoirs. When full, they could store energy equivalent to almost two years of consumption. With increased load and the impossibility of adding new reservoirs to the pace of the demand growth, the period covered by the reserve declined over time, currently reaching around five months – which is still a world record. (This relationship does not consider any other source. For example, if it is possible to define an alternative source for hydropower with reasonable costs and responsible for 25% of the load, the reserve compared to the "net" consumption, minus the non-hydraulic source, rises to seven months.)

As it is well known,a significant reduction in the costs of new sustainable sources is under way, especially solar and windpower. In this new context, the differential of the Brazilian system may still remain the size of its energy reserve.

This characteristic brings another operational singularity: in Brazil, it is necessary to decide not only where, but also when the energy must be generated. Every drop of water held in reserve contains a challenge: when should we use it? This dilemma does not exist in the thermal-based systems.

Figure 8 | Energy exchange between the Southeast and South regions



The attempt to fragment the system

The 1990s saw the decision to deploy a model based on competition rather than cooperation, fragmenting something that had always been dealt with globally. This endeavour required a high degree of mimicry of the thermal-based systems. With an electrical system characterized by unique features, Brazil decided to ignore its specificities and implant one competitive model for energy and power plants. It was a very problematic process.

The insistence on error and the absence of structural revisions, always under pressure from commercial interests, turned both consumers and Eletrobras into victims when trying to "fix" the defects of the new model that appeared in sequence.

From the beginning of the process, technicians of the sector knew that it would be almost impossible to implement a system in which plants compete among themselveswith the energy generated by each one. As the optimal generation strategy depends on an overall view, individual decisions would cause conflicts and inefficiencies. How can a hydropower plant be obliged to generate energy and to store water at the same time?From the plant's perspective, the first demand depends on the market, while the second stems from the monopolistic perspective of the National Operator, which analyses the whole system. In the Brazilian case, not even plants on the same river belong to the same company. Conflicts could occur already in the first stage, as shown in Figure 2.

Trying to solve these conflicts, a complex and subjective methodology was implemented with the issuance of a certificate that theoretically represents the contribution of each plant to the total capacity. Based on this certificate, each plant receives permission to commercialize its own energy. The system is purely financial and virtual. It depends on subjective accounting arrangements. It is so complex that an analytical text would be unfeasible. We will list three major differences with truly competitive energy systems:

1. In thermal-based systems, the sum of the individual capacities defines the total capacity. In the unique Brazilian system, the opposite occurs: the total is first defined and then a portion allocated to each plant is established.
2. Since the proportion of hydropower plants is significant, and we have a tropical hydrology, there is a statistical uncertainty when defining a single amount in the issuing of the certificate.
3. Given the existence of large reservoirs and the uncertainty about future inflows, the reserve's estimated trendsshow the possibility of an energy deficit. Therefore, it was necessary to estimate a subjective parameter, the cost of this deficit for the entire country. It started to influence short-term values, since it varies at each level of the reserve: the lower the level of the reservoirs, the greater the influence of the deficit cost.

This is a sample of the huge list of differences in relation to systems in which energy production generates real competition.

Against all the evidence, the country adopted the individualization of energy frompower plants. Regardless the origin of its primary energy (hydro, thermal, wind or solar), each plant was associated with a certificate issued by a mathematical model that calculates a "physical guarantee", the supposed contribution of each plant to the total energy supply. This amount started to define the bids in most projects. The extremely complex calculation methodology contains large vulnerabilities.

Since the concession period of the plants is thirty years, those that had already been in operation when the model was implemented received the certificate of physical guarantee at a time in which the reservoirs provided greater comfort, because the energy demand was approximately half of the current one and the strategy of operation was different. Since then, the parameters that define the division of the total guarantee by each plant have been changed. However, since there are commercial interests fixedin contracts, the values cannot be changed.

The evident inconsistency among physical warranty certificates, issued decades between them, generated an overestimation of the total capacity, since the certificates were never revised. This led to costs for the consumer, because the optimism of the "guarantee" must be compensated with the construction of other plants. The solution was to promote "reserve energy" bids paid through charges. But how can something called "physical guarantee" need reserve energy? In fact, the "reserve energy" attempts to correct the overvaluation, which imposes a greater risk than what is adopted by the plans. From 2008 to 2017 this overcharge reached R$ 150 billion.

Let's analyse two examples of "physical guarantee" certificates, compared to actual generation in the last fourteen years.

Inaugurated in 1963 in Rio Grande (MG), the Furnas plant has 1,216MW of power. Figure 9 shows the average generation of the plant in average MW (average MW is the average energy in any unit of time; in the case of the monthly data, each average MW is equivalent to 730 MWh, since on average each month has 730 hours). In the Brazilian mercantile model, the fixed magnitude called "physical guarantee" of Furnas is a 583MW average. In past years it generated well above this quantity, but it has generated a considerably lower volume in recent years.

In contrast to the Furnas plant, Figure 10 refers to the natural gas thermoelectric plant in Juiz de Fora (MG). The physical guarantee of this thermal plant was assessed at an average 78MW, but it seldom reached this amount.

It has been concluded that the physical guarantee of a plant may have little to do with its actual generation. The guarantee is counted as an offer of energy, but in fact the generators are supplied by cheaper plants, especially the hydroelectric ones.

Figure 9 | **Generation (oscillating line) and physical guarantee (straight line) of the Furnas plant**

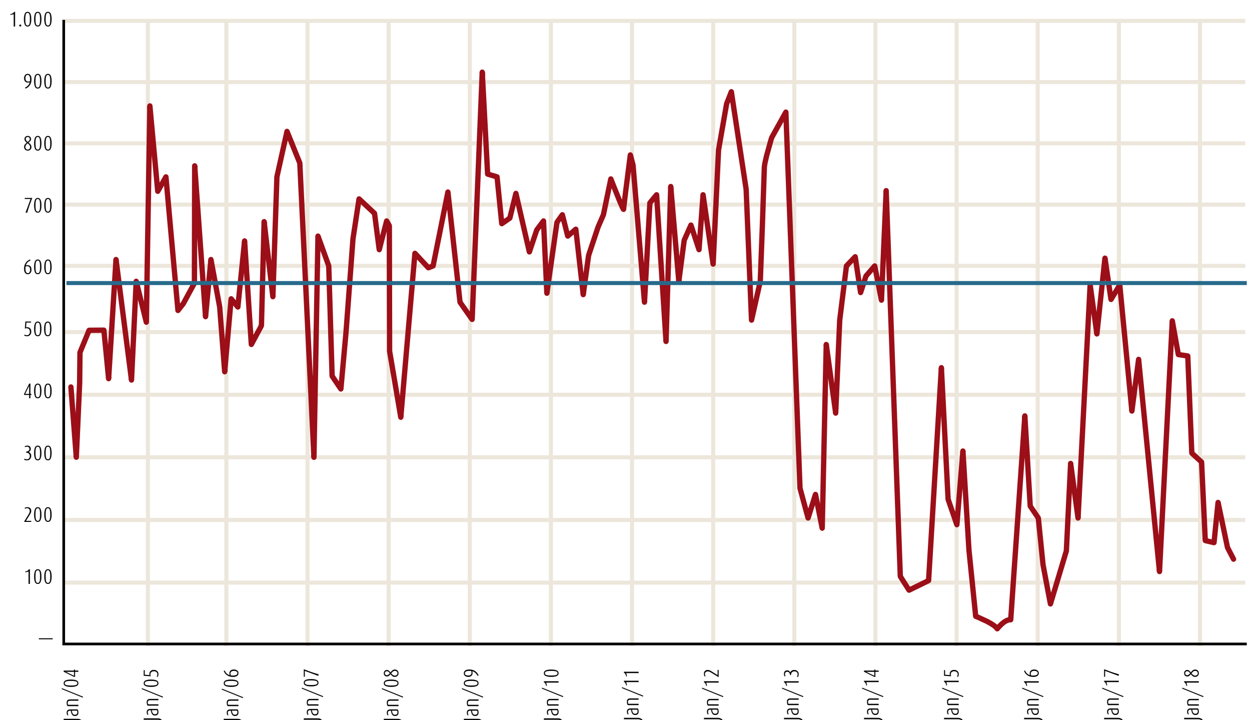
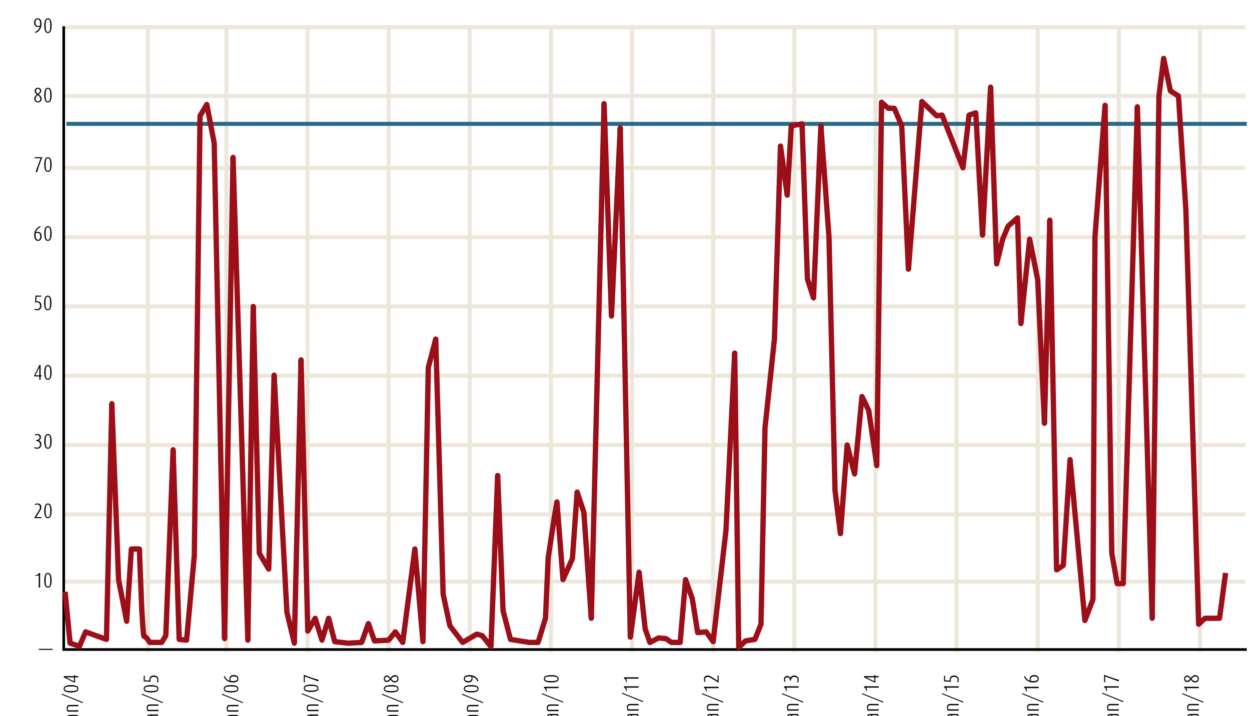


Figure 10 | **Generation (oscillating line) and physical guarantee (straight line) of the Juiz de Fora power plant**



It is impossible to deploy a model in which generators compete with one another based on the energy produced by each one. An optimal strategy depends on an overall view.

This is a very important and little understood aspect. In the Brazilian system, if supply expands with expensive thermal units, it means that part of the water reserve will be used to replace that generation. Contrary to popular belief, some thermal units help in the depletion of reservoirs, depending on the cost of operation.

Figure 11 shows what happens when considering the generation and physical assurance of all the thermal plants in the system (average MW).

The whole area between the blue curve (physical guarantee) and the red one (actual generation) is the guaranteed energy supply in the system. If thermal units did not generate this energy, there would be only two possibilities: either this energy is a "surplus"or the hydropower units generated it. As an example of this substitution, the exchange of energy between thermal and hydropower from 2004 to September 2012 was equivalent to 470 TWh, about 80% of the energy consumed in the system in one year.

The other side of this eccentricity can be seen when examining the same data, but for all the hydropower units (Figure 12). Here we see the inverse situation. Until September 2012, most of the time hydropower generated a quantity above itsphysical guarantee. Since hydropower plants have much lower costs than the thermal units, some issues remain unanswered:

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Figure 11 | Verified generation (in red) and physical guarantee associated to all the thermal units of the system (in blue)

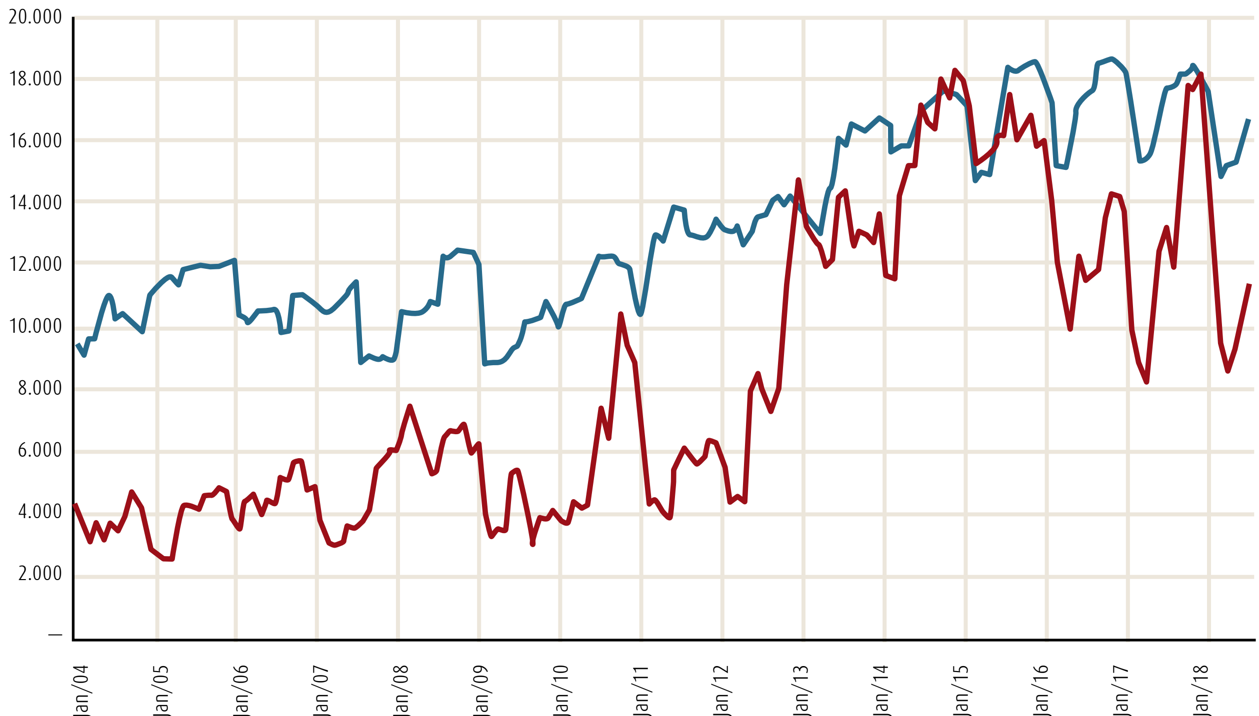
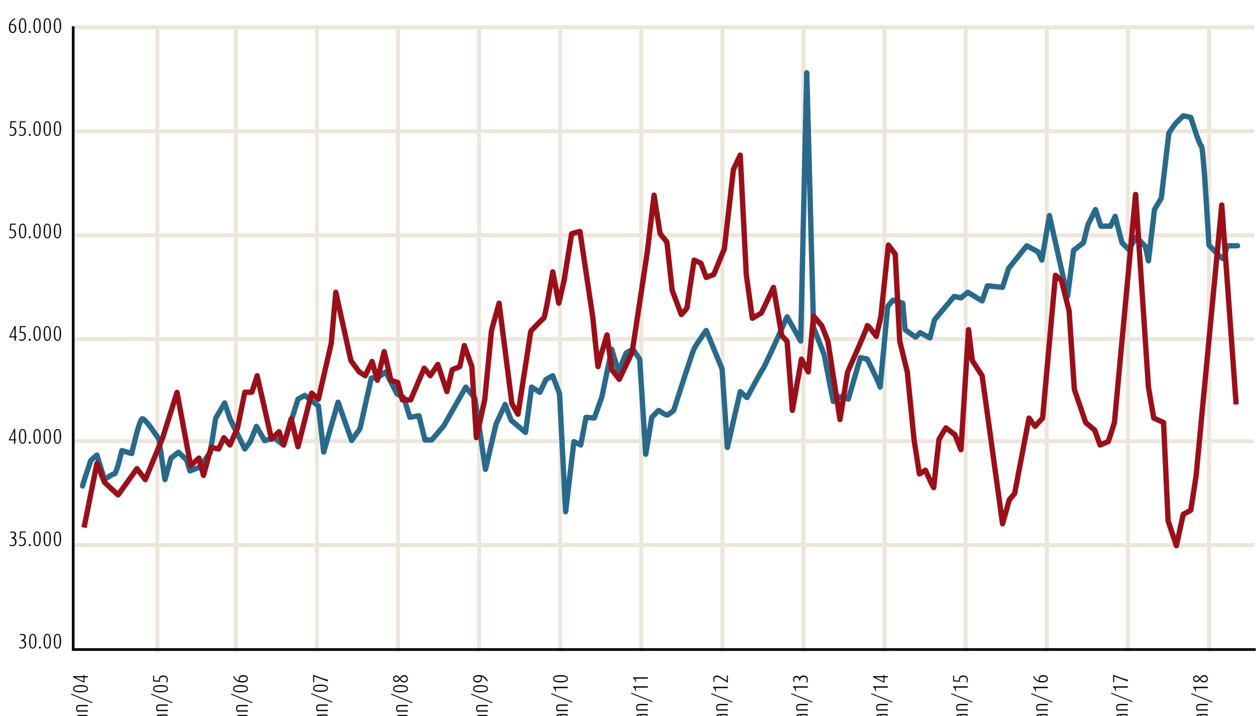


Figure 12 | Generation (in red) and physical guarantee associated to all hydropower units of the system (in blue)



1. If the hydropower units generate a quantity above their physical guarantee and with lower costs, who appropriates the gains?
2. In the last four years, reversing the previous situation, the hydropower plantshave presented a great generation deficit, when using the physical guarantee as reference. What kind of compensation was there between these two opposing events?
3. Why does this change from hydropower surplus to deficit,thereby affecting tariffs, coincide with the Executive Order of the Dilma government (September 2012)?

To understand what happened, it is necessary to understand the Brazilian markets.

The two Brazilian energy markets

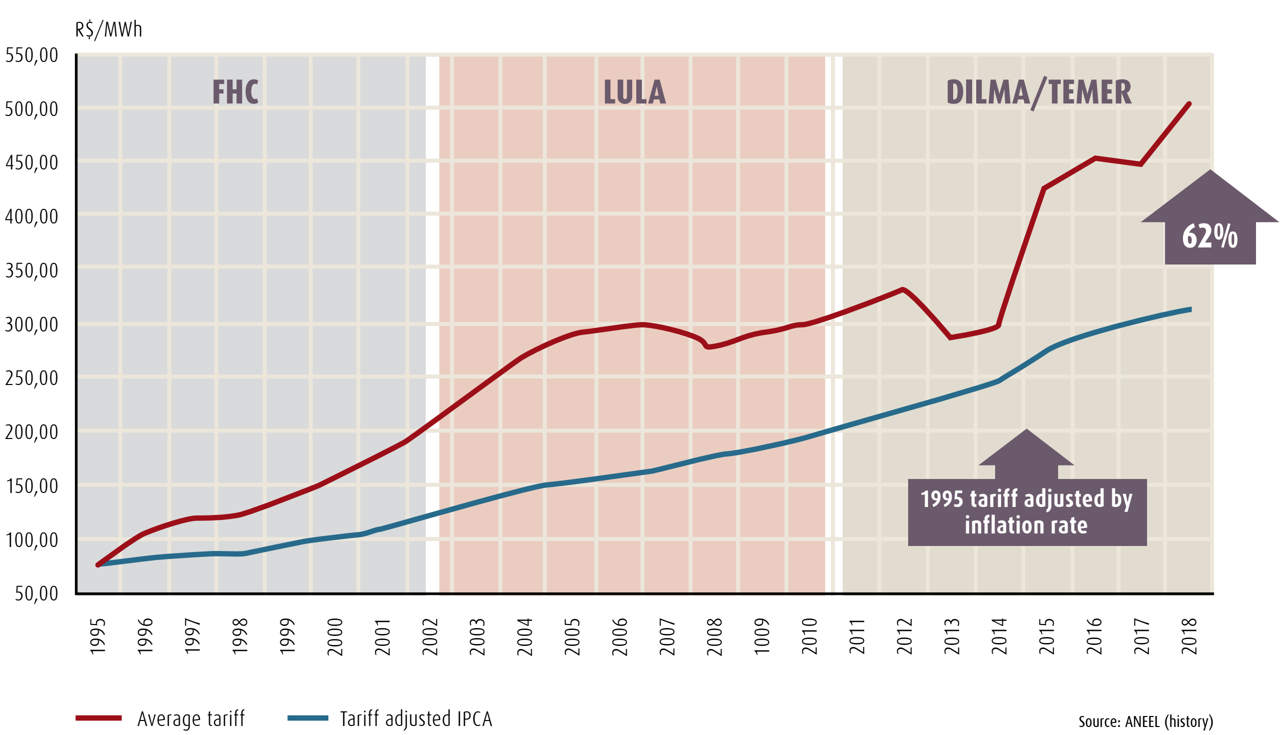
In England, the process of liberation and privatization required fifteen years of study and debate. Brazil – with a much larger territory and a much more complex system – did everything in five years.

The electrical sectors of Brazil and England are very different. Even so, the Brazilian government hired the consulting firm of the English company Coopers & Lybrand that brought us the generic recipes applicable to any system, regardless of physical characteristics, which were in vogue in the 1990s. It was a sort of "one size fits all" of the commercial world. Obviously, the adoption of a competitive model required a considerable adaptation that were unknown to analysts and society.

The privatization was halted by the rationing of 2001 – a tragedy foretold in a country that had stopped investing in the expansion and started selling ready-made plants. In order to hold the investments of Eletrobras, which would be privatized, even transmission lines were no longer built, despite their obvious importance. Why would private companies be interested in investing in new plants if there were ready-made assets to be sold that could generate immediate revenue?

More damage was done when distributors were rejected by the market. Eletrobras had no choice but to absorb them – assuming an issue that had never been its area of expertise.

Figure 13 | Evolution of the average residential tariff compared to inflation rate (excluding taxes)



Source: ANEEL (history)

From ground zero in 1995, Brazil implemented a system of free market and another one of regulated contracting. Commercial relations are established in the regulated contracting environment (ACR, where distributors operate) and in the free contracting environment (ACL, where the large consumers basically are). In the short-term market, the differences between the amounts generated, contracted and consumed are recorded and settled. As we have seen in the examples of the Furnas and Juiz de Fora plants, these differences may be significant. It is quite shocking to verify the price disparities recorded in both environments. Figures 13 and 14 show the evolution of residential and industrial average rates of distributors in three governments.

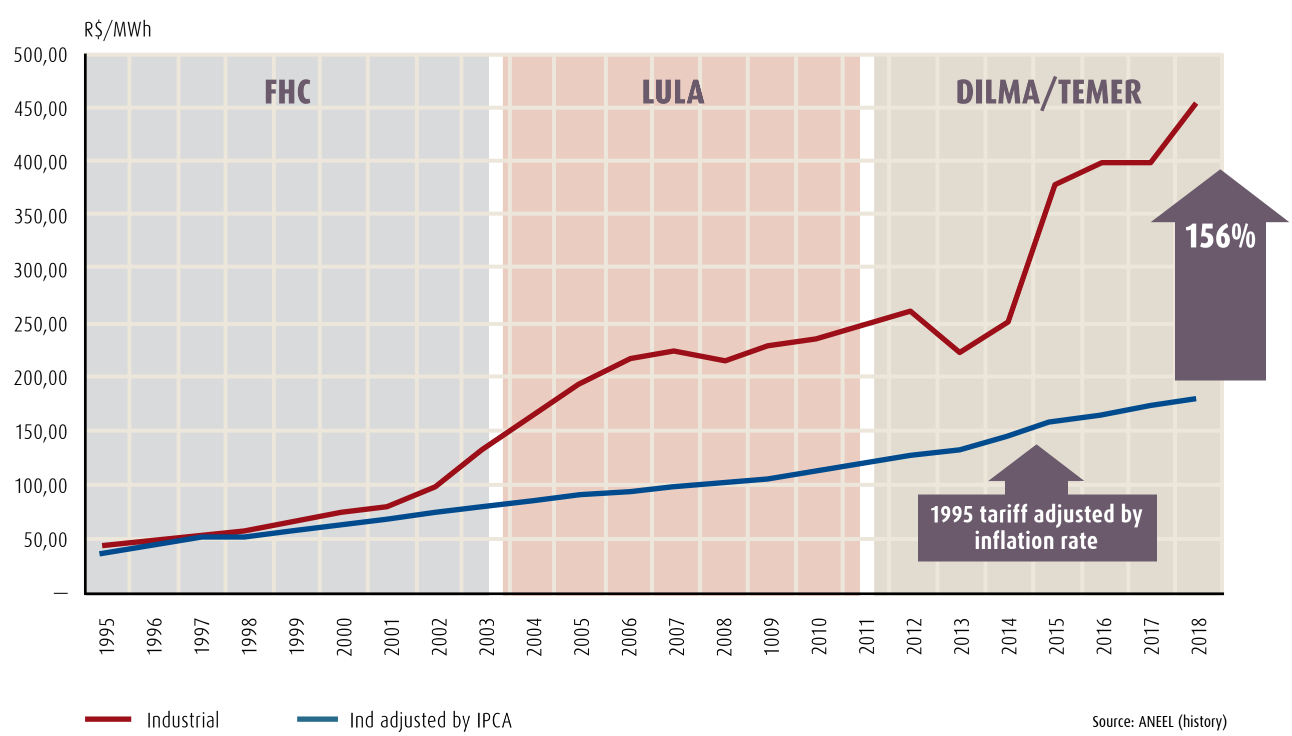
In the homes of the numerous low-income consumers, the tendency for those who do not receive subsidies can be much worse. In the industries, usually the small ones, the price increase is impressive.

Considering all charges, transmission, distribution and taxes, the value of residential MWh reached R$ 1,000.00, at least double the prices practiced in countries with similar configurations, such as Canada and Norway.

It is not possible to obtain the average prices of free contracting environments. It is only possible to collect the difference settlement price (PLD, or spot price), whichis also unique to the Brazilian case. It does not reflect an interaction between buyers and sellers, as in similar markets. The PLD is simply the marginal cost of operation (CMO), a parameter calculated by the System Operator, which is completely unaware of commercial relations. In fact, it is an economic calculation of the value of the MWh reserved in each moment, taking as reference a future scenario of evolution of inflows, the load and even the expansion of the system. It therefore reflects a global perspective of stock control from a monopolistic point of view (Figure 15).

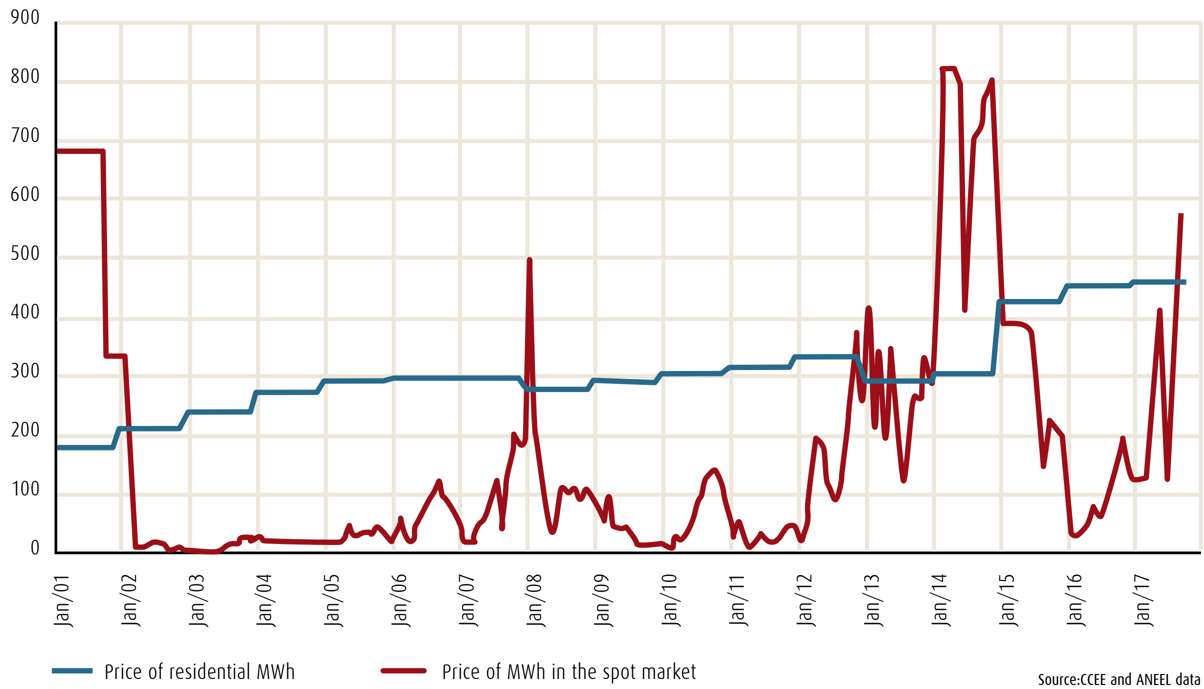
Any comparison of the short-term Brazilian market with other energy markets shows a bizarre outcome. As a result of the configuration of the system and the singular geography, the Brazilian case tends to generate derisory prices. Figure 16 shows in a single chart the comparison of prices in Brazil and in

Figure 14 | Evolution of the average industrial tariff compared to the inflation rate (excluding taxes)



Source: ANEEL (history)

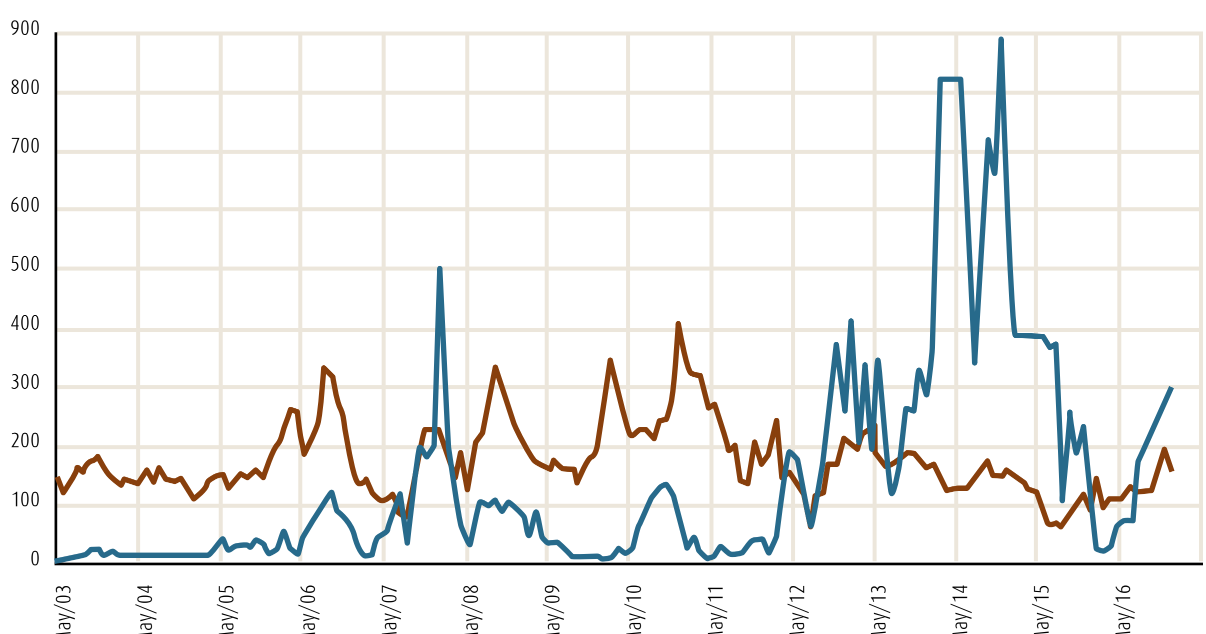
Figure 15 | Spot price (PLD) compared to the MWh price in the residential sector



Source:CCEE and ANEEL data

IT IS IMPORTANT TO NOTE THAT THE RESIDENTIAL MWH PRICE (BLUE LINE) WAS ONCE FORTY TIMES MORE EXPENSIVE THAN THE PLD.

Figure 16 | Comparison between the Brazilian spot market (PLD, blue line) and the Nordpool (red line). Amounts in R$/MWh



the Nordpool market (Sweden, Norway, Denmark and Finland), which also trades hydroelectric energy.

This situation may result from a structural surplus or very favourable hydrological processes. Being appropriated exclusively in the free market, it produces speculative behaviour. A non-transparent market appropriates surpluses and above-average kinds of hydrology. Monthly "contracts" commercialized in the free contracting environment exceed 25% of the total energy in some years. There is a dangerous incentive to avoid-contracting long-term supply, resulting in disastrous consequences for the system balance.

The fragmentation of responsibilities was the other important result from the adoption of the model. Currently, the following institutions deal with the same problem:

1. National Energy Agency (ANEEL), a state company under a special regime, linked to the Ministry of Mines and Energy, created to regulate the Brazilian electricity sector (Law 9,427/1996 and Decree n. 2.335/1997).
2. National System Operator (ONS), responsible for coordinating and controlling the generation and transmission of electricity in the National Interconnected System (SIN) and for planning the operation of isolated systems in the country. It is supervised and regulated by ANEEL. Established as a legal entity under private sector law and a non-profit civil association, ONS was created on August 26, 1998 by Law 9,648, amended by Law 10488/2004 and regulated by Decree N. 5.081/2004.
3. Electric Energy Trading Chamber (CCEE), responsible for accounting

The manner in which the "physical guarantee certificates" have been issued has created an unrealistic assessment of the total capacity of the system. The risk is greater than what is admissible in the plans. This imposes billions of *reais* on consumers.

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and cash settlement in the pot energy market. It calculates and informs the settlement price of differences (PLD) used in the energy purchase and sale.
4. Energy Research Company (EPE), which provides services to the Ministry of Mines and Energy (MME) in the studies and research area to subsidize the sector planning, including electric energy, oil and natural gas and its derivatives and biofuels.

These entities have frequently presented conflicting criteria and represent an additional cost.

The necessary energy

Analysing the data from in Figure 17, it is clear that the country needs an average of approximately 2,200 MW annually to maintain the balance. This amount is equivalent to the production of a plant like Xingó on the São Francisco River, or two plants like Itumbiara on the Paranaíba River, or four plants like Termo Pernambuco. On the other hand, average Brazilian residential consumption is low, around 150 kWh/month. Many residences of low-income families consume less than 100 kWh/month, about the consumption of a refrigerator, some lamps and a fan. The need for energy will grow according to the increase of Brazilians' income. At present, it is not possible to confidently state that an increase in demand – whether by resuming economic growth or by increasing family income – will indeed occur.

The singular and eccentric Brazilian model of the 2000's brought with it some strange behaviour. The plants generated energy (or not) regardless of whether they had been contracted (or not) in the market, since they weredispatchedfrom the general perspective by the National Operator that viewed the system as a whole. The Operator ignored the contracts.

With reduced demand shortly after the rationing in 2003,Eletrobras' power plants generated energy with no contracts and they were remunerated forthe MWh at spot prices (PLD). During this period, PLD ranged from R$ 4/MWh to R$ 20/MWh. Unlike the other companies that lost contracts, Eletrobras was forbidden from operating on the free market to mitigate the loss. The company was used to foster the free contracting environment. The 2003 derisive prices practiced on the spot market were due to the disengagement of existing plants, most of them belonging to Eletrobras.

These extremely low spot prices lasted until 2012. This led the free market to a speculative and merely conjunctural behaviour. Representing 30% of the total, this scenario saw no contracting of construction companies for any new large-scale plants, except for wind energy.

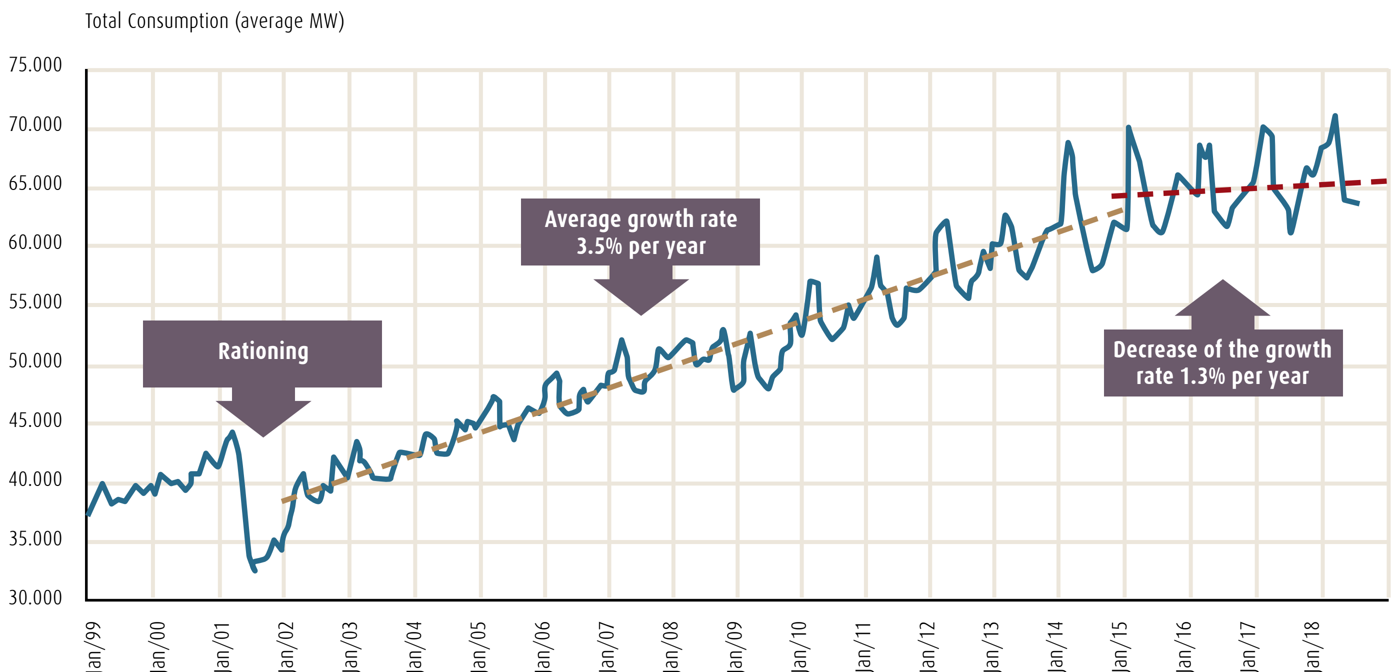
The model adopted imposed all the responsibility of long-term contracting on distributors and reserved part of the energy of future projects to be negotiated on the open market. Due to the speculative bias of this market, many projects were evidently remained uncontracted.

This model caused other problems. Figure 18 shows the physical assurance of all sources of generation and total electricity demand. A "tangency" of the total load and the total guarantee is noticeable during the 2009-2013 period. However, as previously mentioned the modelling defects caused the guarantee to be overestimated, promoting the risk of shortages, avoided by three factors:

Due to the economic recession, the total load has been stagnant since 2014. Even so, for more than four years the reservoirs have not been filled. The system is imbalanced. The contracting of expensive thermal plants requires hydroelectric plants to generate more energy.

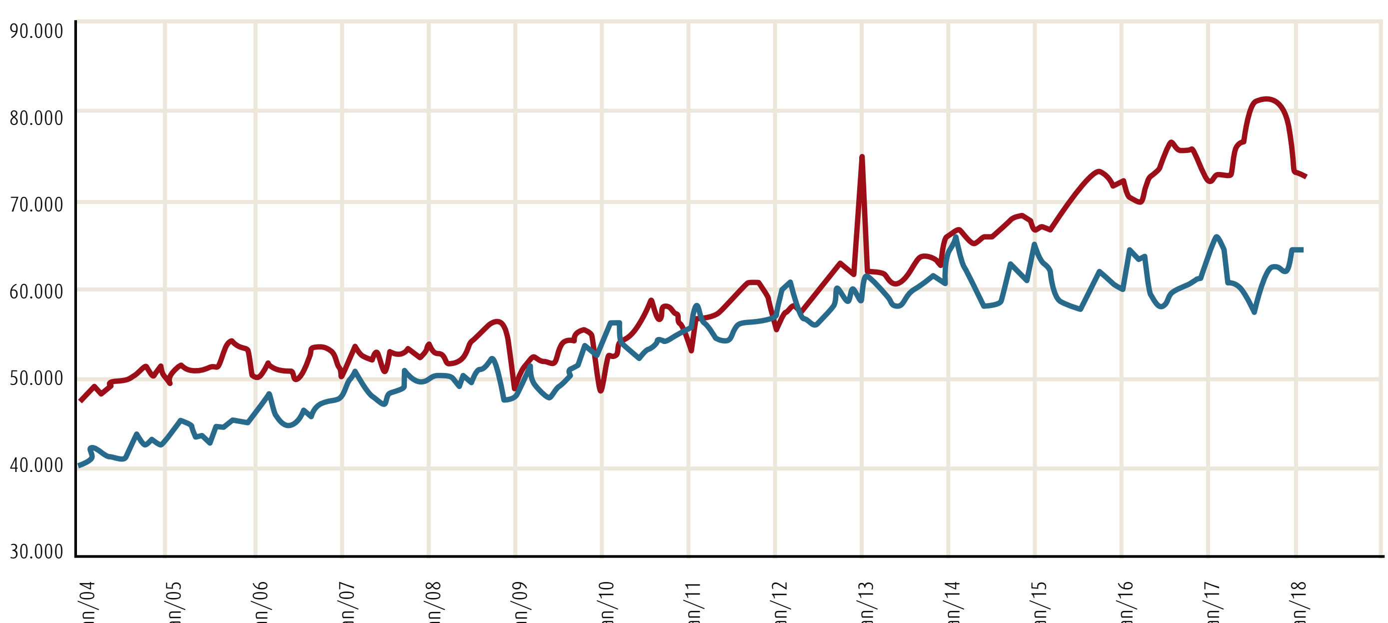
1. Hydrology was exceptional (30% above average) in 2009 and 2011. Structural imbalances of supply and demand can be affected by above-average hydrology.
2. Eletrobras was once again used by the government when it realized that the free market would not ensure the necessary expansion, imposing partnerships in which the institution was a minority shareholder to facilitate projects that required contributions of around R$ 3 billion/year.
3. A temporary solution was the use of reserve energy bids financed by taxes, thus compensating the overestimation of the guarantee of the existing plants.

Figure 17 | Evolution of consumption and electric power load of the interconnected system



IT CAN BE SEEN THAT: (A) THE 2001 RATIONING CAUSED A REDUCTION OF 25% IN THE ELECTRICITY CONSUMPTION; AFTER RATIONING, THE EVOLUTION OF CONSUMPTION REMAINED 15% BELOW THE PREVIOUS TREND; (B) ONCE THE SITUATION NORMALIZED, AN AVERAGE GROWTH RATE OF 3.5% PER YEAR IS OBSERVED; (C) THE DEMAND GROWTH WAS DRASTICALLY REDUCED DUE OF THE INTENSE ECONOMIC RECESSION BEGINNING IN 2014.

Figure 18 | Evolution of the load (blue curve) and the physical guarantee of the system (red curve)



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There was an implicit transfer of costs, since many of these projects provided profits for the private partner and losses for the state company (Eletrobras' level of indebtedness increased significantly, intensified by its exposure in the open market, which prevented it from taking advantage of new contracts; even with positive return rates, the projects did not reach the state's cost of capital).

In 2012, the industry scenario was inexplicable: explosive tariffs;the beginning of defaultsin the open market; reserve energy charges of R$ 150 billion (accumulated since its implementation in 2008); delays in the construction sites; lack of coordination between transmission and generation projects; significant increase in transmission costs and regulatory instability.

The continued rise in prices rattled the industry. In 2011 the Federation of Industry of the State of São Paulo (Fiesp) launched a campaign blaming Eletrobras' prices for the tariff increase. Since most plants were old, it was argued that consumers had already paid for these units, which were amortized. The thesis of the amortization was indeed true; however, it drew attention away from all the other causative agents of the price escalation when so separately highlighted. The campaign contained a series of misconceptions:

1. The prices practiced by Eletrobras were not defined by the state company. They were the result of a bid of energy from existing plants, carried out in 2004. These values were around R$ 90/MWh.
2. Therefore, with the market model the concept of "tariff" that accounts for the level of

amortization of investment was replaced by the concept of "price".

3. The concept of price obtained in bids, which is still adjusted by inflation indexes, was the government's choice and well-known by private players.
4. Bid prices for plants under construction (Santo Antônio, Jirau, Teles Pires) were used to make comparisons (a major misconception that soon appeared in the monumental deficits of these plants with defined prices, due to the frustration of the assumptions about the conclusion of the works and commercialization on the open market).
5. In fact, the amortization is not related to the concession period. It is simply an accounting calculation that is applied in several countries. It was used in Brazil as "service by cost" and in most American states as "return rate regulation" (theoretically it is possible for a plant to amortize its investment before the termination of the concession period).
6. The 1995 low tariff was in fact justified by this system. In other words, at that time consumers could already benefit from this effect.

The government surprisingly accepted Fiesp's thesis and anticipated the end of the concession period, which would end in 2015. Instead of using the data accounted for in the Eletrobras reports, the government rejected the data from the Regulatory Agency and the accounting auditors, implementing a mathematical model which imposed the costs of operation and maintenance on the plants. Thus, the plants were no longer "assets" of the company, which became a simple operations manager of the plant.

There was a reduction of almost 90% in the values practiced in the bids. The inconsistent methodology disregarded the information of the company itself and established a price based on a databank formed by plants very different from the target ones.

Figure 19 specifies the tariffs imposed by Executive Order 579, transformed into law 12,783/2013, for each Eletrobras plant.

The average tariff obtained by weighing the physical guarantee of each plant was R$ 7.67 MWh, which was equivalent to US$ 3.20 MWh on the date of the technical note, a world record of low prices.

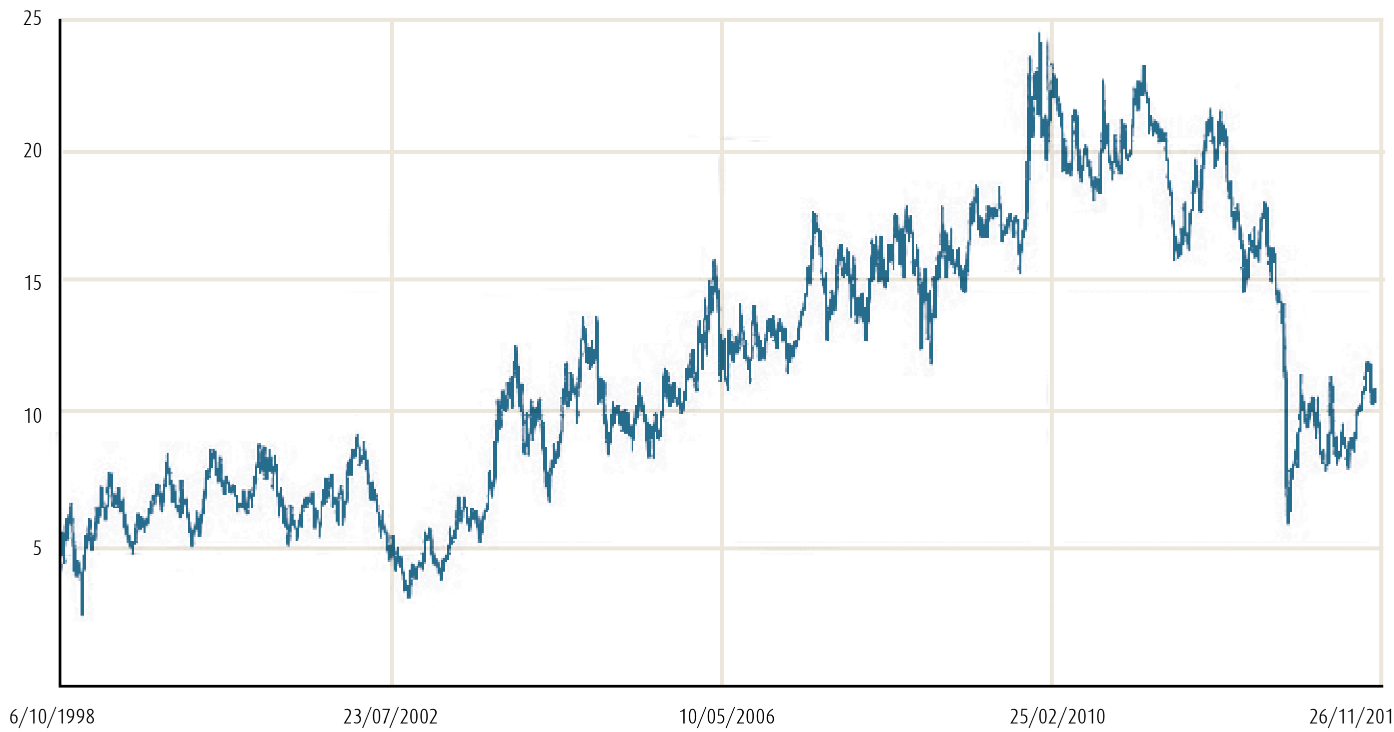
There were significant consequences:

1. This governmental option undermined Eletrobras and ignored all the other factors of price rising, such as the establishment of several charges, the increase in the cost of transmission, the reserve energy and the appropriation of income by the low-price bias on the open market.
2. By isolating the plants and the companies, the central administration lost support from the income of these assets. It was clear that the accounting losses would be significant. The most shocking example of this decoupling

Figure 19 | Tariffs imposed by provisional measure 579, transformed into law 12783/2013, for each Eletrobras plant

Plants	Power (MW)	Imposed tariff R$/kW Year	Physical Guarantee (MW average)	Final tariff R$/MWh
Funil	216	66,59	121	13,57
Boa Esperança	237	66,74	143	12,63
P Colômbia	319	60,94	185	12
Corumbá I	375	57,59	209	11,8
Estreito	1048	41,58	495	10,05
Furnas	1216	40,6	598	9,42
Marimbondo	1440	39,22	726	8,88
Itaparica	1479	42,67	959	7,51
Xingó	3162	35,61	2139	6,01
P Afonso	4279	29,92	2225	6,57
Total	13771		Average	7,67

Figure 20 | ELB stock price (-70%)



is the Eletrobras' Electric Energy Research Centre (Cepel), which was maintained by the revenue from the generation and transmission assets.

3. Even worse was the annihilation of the traditional self-financing capacity of the electricity sector. In the applied conception, an old plant that is managed only by the costs of operation and maintenance does not generate any financial benefit for the construction of new plants.

Figures 20, 21 and 22 show the massive and sudden fall in the value of Eletrobras.

Even with around 14,000MW of hydro-electric power plants (around 16% of the total) charging only for basic costs (approximately R$ 35.00 MWh, including charges and taxes), the tariff value did not stop rising for several reasons.

A "tariff flag" was created to cover costs of thermal generation, including fuel and diesel plants contracted in 2008. According to ANEEL, this is a "flag" that can add up to R$ 50/MWh to the valid price.

In a country where most of the electricity comes from rivers, the easiest way to justify a water crisis is blaming the lack of rainfall. Figure 23 shows the 20 worst years of the history of inflows for each region of the system.

Only in the Northeast region was natural energy the worst in history. By the current criterion, only this region is at risk. The Southeast region receives most of its energy from rivers and the low inflow levels were concentrated in the 1950s, known as a critical period.

Difficulties have been mounting. The situation of the hydroelectric sector is generating a great legal controversy, due to the individualization of the guaranteed energy of the system per plant that results in a sequence of problems:

1. The physical guarantees of the plants were determined on different dates with a methodology that was changed several times and contained subjective parameters.
2. The companies did not participate in the setting the amounts.
3. The plants auctioned were evaluated precisely for this magnitude.
4. The generation of the plants is determined by the National System Operator (ONS), which, as we have seen, operates from a global and

Figure 21 | Return on invested capital (-13%)

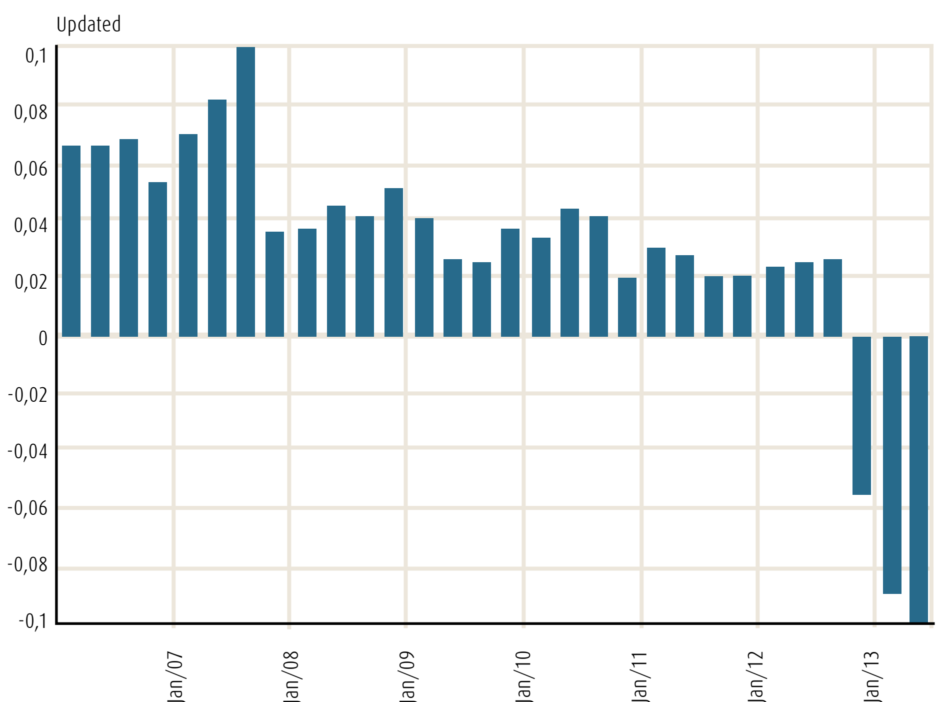
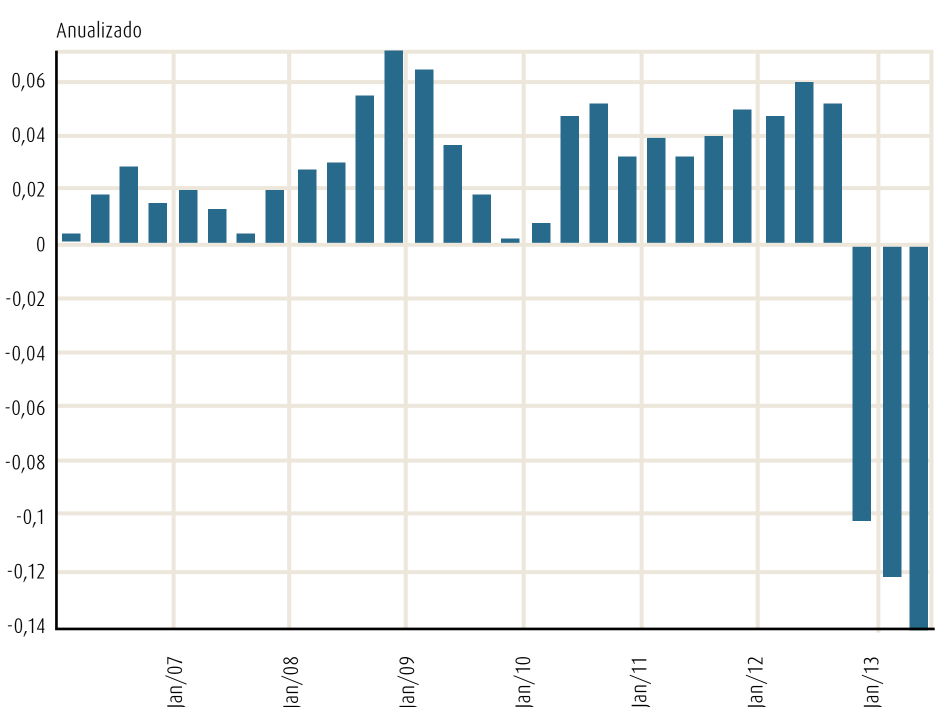


Figure 22 | Return on net equity (-30%)



monopolistic perspective and does not recognize contracts.

5. By order of the ONS, generation was reduced drastically in the 2012-2018 period.
6. To meet their contracts, the hydroelectric plants faced a huge energy generation deficit. By the current model, they are forced to acquire the energy deficit in the market, paying the price of much more expensive thermal energy. Called Generation Scaling Factor (GSF), this dilemma has already caused defaults of more than R$ 9 billion.
7. The plants affected by the reduction of tariffs through Law 12,783/2013 transfer this deficit to the distributors, further aggravating the country's tariff situation.
8. Even with so many problems, the private sector cannot complain about low returns in this extremely essential sector. Financial data show that until 2014 the electricity sector ranked second in the positioning of dividends paid to shareholders, being surpassed only by the banking sector. This position shifted to third place after 2014.

The current situation of the energy reserve is shown in Figure 24. It is noticeable the reservoirs have not been filled for the past four years – further evidence showing that the system is unbalanced, since the total load has been almost stagnant since 2014.

As previously mentioned, the contracting of expensive thermal plants (oil and diesel) required higher generation of hydroelectric plants. This is one of the causes of the emptying of the reservoirs.

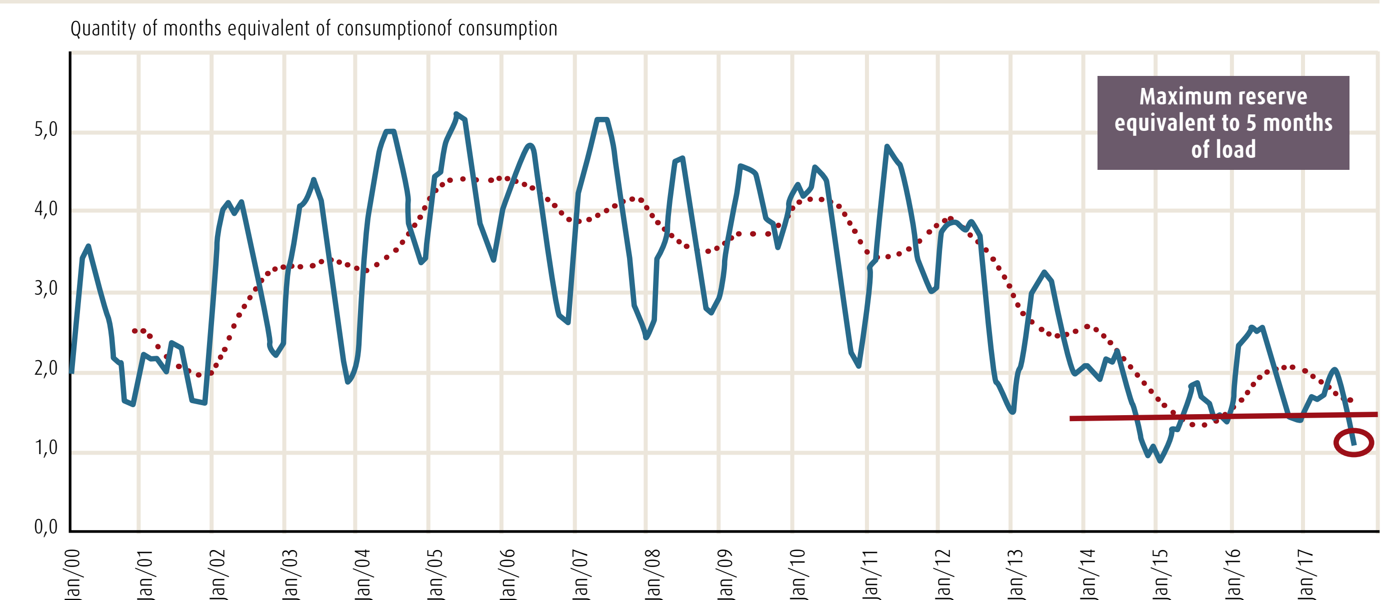
Figure 23 | Affluence per region in selected years

	SOUTHEAST		NORTH		SOUTH		NORTHEAST	
ORDER	YEAR	ENAT	YEAR	ENAT	YEAR	ENAT	YEAR	ENAT
1	1971	27.342	**2016**	3.960	1945	3.206	**2017**	2.424
2	1955	27.382	1953	5.165	1944	3.413	**2015**	3.295
3	1953	28.310	1998	5.259	1968	3.696	**2016**	3.517
4	1954	28.690	**2017**	5.423	1933	4.024	**2014**	3.843
5	1969	29.303	1951	5.510	2006	4.402	2001	4.004
6	1934	30.443	1971	5.593	1949	4.729	2010	5.005
7	1936	31.802	1962	5.642	1978	4.828	1976	5.223
8	1963	32.178	1955	5.721	1962	5.498	**2013**	5.244
9	1944	32.189	**2015**	5.891	1934	5.750	1971	5.278
10	**2014**	32.551	1987	5.896	1991	5.821	1996	5.423
11	1964	32.833	1972	5.904	1985	5.850	1998	5.506
12	1968	33.085	1952	5.933	1943	6.058	1955	5.530
13	**2017**	33.090	1950	6.130	1952	6.077	2003	5.569
14	1939	33.193	1963	6.221	1964	6.383	1995	5.977
15	1956	33.675	1954	6.250	1951	6.423	**2012**	6.012
16	2001	33.769	1999	6.336	1959	6.452	1999	6.052
17	1938	34.201	1976	6.445	1981	6.603	1959	6.066
18	1941	35.709	1993	6.644	1940	6.764	1987	6.149
19	1975	35.721	1932	6.659	1937	6.813	2002	6.174
20	1970	36.285	1984	6.669	1974	6.863	1953	6.206

INFLOWS ARE TRANSFORMED INTO ENERGY (AVERAGE MW), ASSUMING THEY WILL BE TURBINED (ALTHOUGH IT CAN UNDERGO CHANGES IN THE REAL WORLD, THIS TRANSFORMATION OF UNITS IS MORE USEFUL TO COMPARE ENERGIES). THE YEARS CONTAINED IN THE "CRISIS" PERIOD (2012-2017) ARE MARKED IN RED.

ENAT = Natural Energy

Figure 24 | Trend of the reserve in quantity of months/load



Source: ONS data

Conclusions

When a generation system depends on nature in tropical countries, the primary types of energy (river flows, wind and sun) vary greatly. In a country of continental dimensions, these significant variations do not coincide. Thus, assigning a fixed value per plant to mimic the formation of prices in a thermal system (which depends only on fuel) has no theoretical basis.

Even the alleged advantage of competition is reduced, since plants sell energy that they themselves do not generate. Therefore, efficiency is relegated to a secondary priority.

Currently, there are about R$ 90bn in costs from modelling that have not yet been charged to the consumer – the so-called "skeletons" that will haunt electric bills for a long time.

The origins of this situation are diverse: water deficit in hydroelectric plants; unpaid compensations arisen due to the intervention of the Dilma government; deficits in the tariff flags that cannot cover the thermal cost; subsidies for the social tariff; subsidies for thermal plants of the isolated system; and Eletrobras debts related to distributors rejected in the privatization of the 1990s.

The proposals currently under discussion promise more market and less coordination, which is the opposite of the logic outlined in this text. This will require more eccentricities and complexities – with no reduction in tariffs, regulatory stability, financing capacity or energy security.

With Eletrobras nearly insolvent, we run the risk of repeating the 2001 experience, when capital was concentrated on acquiring ready-made assets, thereby abandoning expansion.

Given the favourable Brazilian geography and nature, something very amiss has happened here. Complexity is not only cost-generating, but also a powerful tool for disinformation – one of the great evils of Brazil nowadays.

Unfortunately, individualization – a concept increasingly implemented in many economic activities under the approach of radical liberalism – conflicts with the uniqueness of Brazil's geography and climate. The great technological advance the countryhas made in previous decades by forming an interconnected system is being lost.■

OUTLINE OF AN ALTERNATIVE

The power of electric mills are fixed values that are registered in turbine and generator manuals. They do not depend on external bureaucratic criteria.

By making power plant revenues proportional to their power, they would have constant and guaranteed revenues, which would encourage investors to upgrade constantly. The hydropower investor would not assume the billion-dollar hydrological risk that is taking place today. The thermals would be remunerated by the power plus the cost of the fuel in the event of a dispatch, considered cases in which inflexibilities occurred. As a significant part of the sources would be contracted by power, the revenue would be the same regardless of hydrology. Therefore, under exuberant hydrology, the extra revenue from higher generation at lower cost would belong to all consumers. A compensation fund for adverse hydrological situations would be possible. In this system, there would be no situation in which surpluses do not compensate for deficits, as shown in figure 12.

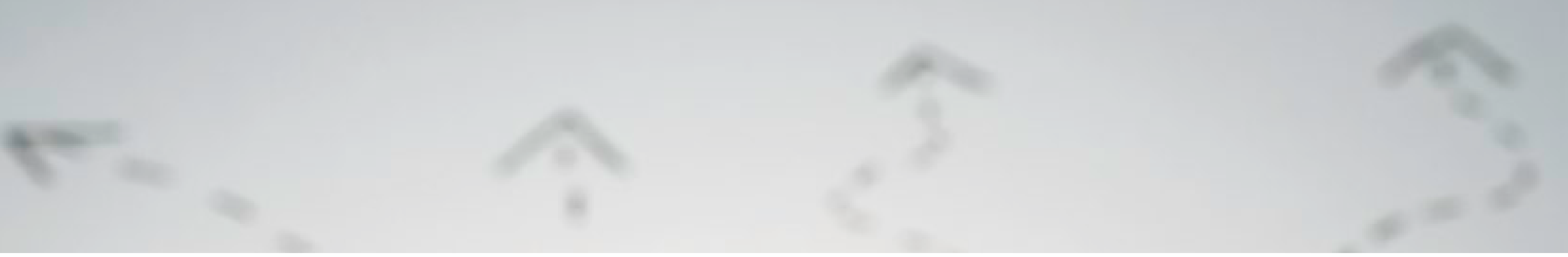
An energy market could exist, provided that it was actually the fruit of the interaction of suppliers and demanders. There would be no settlement of generation differences at the marginal operating cost (MOC) price. Changes in the operating criteria would not affect the commercial world, since they would be changes to the internal methodology of the majority buyer.

The “physical guarantees” of the plants would be possible, but they would be guiding parameters of the contracting policy and could be changed without problems.

This proposal was presented to the Lula government, but ran into political difficulty: it requires the definition of an agency that would contract the MW needed for the system to guarantee the MWh of consumption. According to the government, the “market” would see this as “nationalization”. This prejudice is unfounded. For in making the expansion plan, the government, through its various institutions, does exactly what this contractor would do. In fact, the model already exists for transmission, so that this role could be done by one of the already existing agencies.

Joining the planning and operation institutions had also been proposed, since the planning process depends on operational simulations. We would avoid the current discrepancy of criteria between EPE and ONS with this plan.

In fact, Brazil already had the situation that is beginning to emerge in the thermal base countries that face the entry of wind and solar sources that are not dispatched and absorb the market for the dispatchable thermal energy. Due to the volatility of demand and prices, these markets have given preference to power contracts instead of competing for energy.



SCIENCE, TECHNOLOGY AND INNOVATION

Brazilian policies in the 21st century

T. DALLAS/SHUTTERSTOCK.COM

We should not mimic the policies of developed countries. The Brazilian agenda needs to keep the social dimension at the centre of its concerns, encouraging technological research focused on local problems and the provision of essential goods and services, such as food, health, education, housing, solid waste management, access to drinking water and energy – and even culture. Science and technology policies must take into account the territorial dimension of Brazil. Instead of producing goods that are intensive in non-renewable natural resources, we must value the new paradigm of sustainability. All this should be part of a new national development project that highlights the specificities of our country.

Introduction

The Brazilian industry has been losing density and dynamism in recent decades. This fact is associated by some authors with the expected effects of the austerity policies, the exchange rate appreciation, the high interest rates and other elements of restrictive macroeconomic policies, as well as the increase in commodity prices resulting from the so-called "China effect".

In this article we enunciate that such factors exacerbated some phenomena already evident in the 1980s and 1990s. After internalizing the benefits of the Second Industrial Revolution, the Brazilian industry should face a restructuring process that could incorporate the current socio-technical revolution. The deepening of financialization, the reorganization of the productive activities and of the large transnational corporations, as well as the global crisis initiated in 2007-2008, aggravated the situation and added new challenges. The positive highlight was the set of policies adopted by Brazil to deal with the initial stages of the crisis, particularly with the performance of the five official banks, which ensured the productive investment and survival of the main companies. There were also changes in geopolitics introduced by the forging of alliances, such as the BRICS. Such characteristics cannot be ignored when discussing the current challenges of productive and technological development in Brazil.

Obviously, to fulfil the promise of becoming the "driving force of development" (Freeman 1982), science, technology and innovation (ST&I) need to be used by the productive sector. This article resumes the discussion about the Brazilian ST&I policy based on these considerations. The text is organized as follows: item 2 gives a brief analysis and evaluation of the Brazilian policy; item 3 presents a

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synthesis of the main transformations of the Brazilian productive and innovative structure, showing how, in spite of the policies implemented, the problems perceived since the millennium transition were confirmed; item 4 discusses the policy implications from a contextualized and systemic view of innovation. Finally, we reach the conclusion section, presenting policy suggestions.

Brief history of Brazilian politics on science, technology and innovation

The Portuguese exploitation of Brazil between the fifteenth and eighteenth centuries prevented any productive activity in the colonized land, avoiding competition with those that could be carried out in Portugal (or in its trading partners lands), as well as any academic or research activity. Unlike the experience of Spanish America – in which a university emerged soon after the conquest in Santo Domingo in 1538 – the first college courses (Law and Medical Sciences) were only implemented in the colony in 1808, when the Portuguese court moved to Brazil. The first Brazilian university – the current Federal University of Rio de Janeiro – was only implemented in the twentieth century. Throughout the second half of the nineteenth century, as monarchy and slavery collapsed, the first Engineering graduation courses (the Polytechnic School of Rio de Janeiro in 1874) and research centres of natural sciences (Emílio Goeldi Museum in Pará, 1885), farming (Agronomic Institute of Campinas in 1887), and health and hygiene (Bacteriological Institute of São Paulo in 1893, Butantã Institute in 1899 and Oswaldo Cruz Institute in 1908)[1] were created.

The creation of these training and technical research centres aimed to meet the needs of the main export activities of Brazil during this period: coffee and sugar. For example, the Oswaldo Cruz Institute, currently one of the most renowned biology research institutions in the world, was only created after foreign vessels threatened not to dock at the port of Rio de Janeiro due to the yellow fever.

A broader institutionalization of the scientific and technological system – and of policy focused on it – only occurred after World War II, following the process of industrialization. The first explicit scientific and technological policy initiatives established the mission of coordinating and promoting scientific research in Brazil with the National Research Council (*CNPq*) in 1951, and the Coordination for the Development of College Graduated Personnel (*Capes*), with the aim of improving college education and guaranteeing the existence of specialized personnel to carry out the economic transformation of the country.

During this period, other R&D institutions were created outside the agricultural and biomedical areas: the Brazilian Centre for Physical Research (*CBPF*), 1949; the Technological Institute of Aeronautics (*ITA*), 1950; soon after, the Technological Centre of Aeronautics (*CTA*). A decade later, research centres were established in state-owned companies: the Leopoldo Américo Miguez de Mello Research Centre (*Cenpes*) of Petrobras in 1963; the Eletrobras Electric Energy Research Centre (*Cepel*) in 1974; the Research and Development Centre (*CPqD*) of Telebras in 1976. During this period, the Brazilian Agricultural Research Corporation (*Embrapa*) was also established in 1973, as well as technological research centres in different states of the Federation, following the model of the Institute of Technological Research (*IPT*) of São Paulo, which was created in 1889.

Still in the 1960s, the Technological Fund (*Funtec*) was created in the then called National Bank for Economic Development (*BNDE*, today *BNDES*) in order to provide financial resources to update and strengthen Brazil's scientific and technological infrastructure, which was to be achieved through the creation of joint research and postgraduate programs, mainly (but not exclusively) in public universities and research institutes. The other important institutional change was the creation of the Financier of Studies and Projects (*Finep*) in 1969, an agency of the Ministry of Planning. When it started its activities, Finep carried out mainly feasibility studies. From 1971 onwards, its role was increased, when it became an executive secretariat of the National Fund for Scientific and Technological Development (*FNDCT*), created in 1969.

The decision to invest in the training of researchers, with public universities as the main institutional base, has brought many advancements, with the consolidation of a significant S&T infrastructure. Over the course of the 1970s around eight hundred new masters and doctoral courses were created, totalling more than a thousand, covering all areas of knowledge (Erber, 1980). The number of masters graduated in 1990 surpassed 5,500 and PhDs, 1,400. However, despite all the planning effort, very limited results were obtained in the promotion of technological development (Cassiolato 2001).

Several studies that examined the technological behaviour of Brazilian private companies in the period (Cassiolato, 1992) found passive innovation strategies, low levels of R&D activity and weak links with industrial research institutes and universities. Large local-owned conglomerates mainly concentrated on raw material processing industries, producing standardized commodities such as paper and pulp, iron and petrochemicals, which required neither significant capacity nor R&D and engineering efforts to add increased domestic value andprogress in the production of more complex goods and services. Instead, they tended to remain in the most elementary processing stages of locally available raw materials. As for foreign companies, their technological efforts were generally aimed at adapting (processing and organizational) products and technologies to local conditions and monitoring technological opportunities and qualified human resources.

State companies played the most active role in the technological development, creating their own R&D and engineering departments to develop specific technologies for the country's environment and resources. In addition to those already mentioned –Cenpes, Cepel and CPqD–Usiminas in the steel industry and Embraer in aeronautics were also the case (Cassiolato and Lastres, 2016).

Industries have used government S&T resources to buy the latest in technology for machines and equipment, but without any commitment to innovation. The results are frustrating.

In the 1970s and 1980s, significant public R&D and engineering centres thus constituted the inner core of Brazil's national innovation system. However, the oil and the international debt crises affected the ongoing transformation in Brazil, which had a significant impact on science and technology (S&T).[2]

The democratic government that began in 1985 created the Ministry of Science and Technology (MCT), including innovation in the political agenda and establishing important human resources programs in the new areas of information technology, biotechnology and advanced materials, as well as reinstating public funding for research at 1970 levels. Nonetheless, the deepening of the inflationary crisis in the 1980s brought considerable institutional instability.

Throughout the 1990s, the deepening of the crisis and the adoption of neoliberal policies relegated the S&T policy to a lower level. The neoliberal industrial policy – based on liberalization, deregulation and privatization – implicitly brought the idea that innovation and technological qualification should be left to "market forces". As summarized by Coutinho and Belize (1996, p. 129), "the hegemony of neoliberal thought instituted a new paradigm in which the predominance of market relations (with privatization and deregulation) would incisively minimize the role that the State should play.Supported by globalization [...] the development policy would be reduced to the creation of proper conditions to attract investors, by maximizing private freedom of accumulation."

S&T returned to the agenda of governmental priorities in the late 1990s,but remained subordinated to neoliberalism. Two initiatives were highlighted: the establishment of sixteen sectorial funds and the beginning of a broad process of states mobilization for the construction of S&T subnational policies, which contributed greatly to the expansion of funding forthe system. However, Brazil was experiencing its "second lost decade", with the increase of the "evil macroeconomic" regimes, "regressive specialization" and loss of productive density.[3] Besides, the guidelines and instruments were mainly based on the mimicking of traditional instruments, some of which had already been adopted for decades, and the new laws of innovation that marked the 1990s scenario in the most developed countries. With rare exceptions, they aimed at creating and enhancing the connections between the industrial sector and universities, through joint R&D projects, which were already implemented in Brazil since the 1970s, but without considerable success.[4]

The 2003 government reintroduced a policy geared for production on the governmental agenda. The main point intended to implement stimuli and promote innovation in companies. There were two basic commitments made with the ST&I area. The first one was to significantly expand public investment to (i) expand and consolidate the national S&T system, with a view to improving its regional distribution; (ii) prioritize R&D in strategic areas; and (iii) better articulate the objectives of scientific and technological development and social development (including support to the consolidation and expansion of local production and innovation systems). The second commitment was to articulate the national ST&I strategy with the other federal policies, especially the industrial policy.

The policy of S&T advanced significantly in two situations: (i) it interrupted the instability of the previous fifty years in the allocation of public resources; (ii) from such stabilization, it provided a significant increase in the funding from federal public resources to the S&T infrastructure. There was also a growing but modest spatial de-concentration of S&T activities.

It should also be mentioned the emphasis given since 2003 to the increase in scientific and technological qualification through significant investment in the creation of new public universities and federal institutions of professional and technological education, in addition to the re-establishment of the existing ones. Since 2003, eighteen new public universities have been created in previously unrecorded regions, in addition to more than 280 federal institutes of education, science and technology, with technical courses, mostly integrated with high school, graduation and technological degrees, specializations, master's degrees and doctorates. These were mainly aimed at mobilizing technological research linked to the specificities and vocations of local and regional development.

The Brazilian policy of supporting the S&T infrastructure presented these and other modest positive results, but the innovation policy continued to be subordinated to the canons of the "institutionalist convention of neoliberal fashion" (Erber, 2011). The Innovation Law followed the proposals upheld by international organizations, such as the OECD and the World Bank, without major changes. It was based on two mechanisms that intended to (a) stimulate the interaction of universities and companies (incubators, innovative cities, technological innovation centres, innovation networks, technological platforms, among others) and (b) reduce the costs of innovation. Much of this was done through fiscal and credit incentives focused on innovative activities, allocated by the Ministry of Science, Technology and Innovation, BNDES and Finep.[5]

As detailed elsewhere in other papers (Cassiolato and Lastres, 2016), the impact of this policy was very modest. The main criticism of these mechanisms is that, since they are generic, they mainly serve to reduce R&D costs in activities already carried out by companies. Moreover, only companies that declare net income can benefit from most incentives; micro, small and medium enterprises do not have access to them. Therefore, the type of policy pursued is, by definition, too limited to encourage new innovation-driven investments. In addition, they are intended for a limited number of agents, activities and regions.[6]

Most part of the support effectively used by the industrial sector was directed towards the purchase of machinery and

We are experiencing a regressive specialization process in which economic activities that are less intensive in science and technology and less able to add value to production are prioritised.

equipment, which actually indicates a technological modernization more than a commitment to innovation. Thus, it is not surprising that data from IBGE's Technological Innovation Survey (*Pintec*) show that, over almost two decades of active policies, expenditure on innovative activities by companies has fallen in relative terms: from 3.89 % of net sales revenue in the period 1998-2000 to 2.80% between 2004 and 2006; 2.60% between 2006 and 2008; 2.37% between 2009 and 2011; and 2.12% between 2012 and 2014. In addition, it should be noted that the subsidiaries of transnational companies are the ones that have benefited the most from tax incentives and financing for innovation, with results close to zero. Despite the benefits received, these companies, for the most part, have diminished R&D and innovation efforts in the country. Even more serious than the reduced commitment to Brazilian technological advancement by these companies is that this was accompanied by a significant increase in

transfer of profits and dividends to their parent companies, especially after the 2007 crisis. Since then, there has been a large increase in these transfers which jumped from the annual average of US$ 5 billion in the period 1990-2005 to a surprising sum of US$ 25 billion per year as of 2007 (values related to 2009).[7]

In conclusion, S&T and industrial policies were not geared to harnessing the progress of social policies, failed to anchor the positive results of the training policy and expansion of the S&T infrastructure and did not prevent the country from continuing loss of its productive and technological capacity. This involution is associated with the very conception of policy, based on exogenous models, with decontextualized application, and outdated, based mainly on a restricted and linear notion of innovation. Its main problem is the absence of a national development project to guide it and give it coherence.

As of 2016, with the deepening of the austerity policies, the importance of ST&I was reduced. The Ministry of ST&I was absorbed by the Ministry of Communications. In addition, there was a drastic reduction of budgetary resources, which challenged the advancements obtained in the previous period and the very survival of the country's education and research institutions.

The increased internationalization of the Brazilian productive structure hampers the local development of technology and innovation.

The structure of Brazilian production

At the beginning of the 2000s, the Brazilian industry was characterized by a fragility that "was reflected in the commercial vulnerability in almost all the industrial areas with greater added value and, mainly, in the areas with sophisticated technological content"; the same fragility was "evident in the traditional industries of non-durable consumer goods" (Cassiolato, 2001, p.7). The explosion of the Chinese development throughout the 2000s and the generation of respectable balances in the Brazilian trade balance – thanks to the increase in the price and volume of our commodity exports – only postponed the revelation of problems already perceptible at the time. Since then and until the present decade, the Brazilian economy and society have undergone many transformations. Social inclusion policies and the improvement in income distribution (but not wealth) have been reversed since the beginning of the decade of 2010, showing the political and institutional fragility of this process. From the point of view of the productive structure, we keep on having a poor competitive performance, with commercial fragility in all segments with high value-added and high technological content. With few exceptions, Brazil is only competitive in activities linked to commodities with large-scale, low value-added production that is intensive in energy and natural resources.

Between 1947 and 1985, the value-added share of the Brazilian manufacturing industry in GDP grew from 19.8% to a peak of 35.9%. Since then, it has been losing ground, reaching 18% in 2003, 13.1% in 2013 and 11% in 2016. In the industrial sector, there is also an inability to incorporate activities that characterize the Third Industrial Revolution. For example, the value of industrial transformation (ITV) of the collection of information and communication technologies (ICTs) has been losing relative share of total ITV in manufacturing industry, dropping from 5.5% in 2000 to 2.17% in 2015. In In terms of GDP, the weight of these industries was approximately 1.4% in 2000, but dropped to 0.97% in 2005 and 0.21% in 2015.[8]

The relative weight of the industrial sector has decreased and the innovative capacity remains low. It is increasing in the weight of sectors less intensive in technology, as well as its dependence on and fragmentation among Brazilian productive systems. This scenario has led to a regressive specialization process (Coutinho, 1997), with important loss at the "core" of the Brazilian industrial network (Cano, 2012). This deindustrialization and the deterioration of the industrial fabric are linked to a development model, implemented in the 1950s and which continues to this day, in which the attraction of transnational companies plays a key role. In the last decades, this has led to a growing denationalization of the economy. Central Bank[9] data show that the stock of foreign capital in the Brazilian industry increased from US$ 41bn in 1995 to US$ 162.8bn in 2005 and US$ 703bn in 2016. The share of foreign capital in GDP increased from 6.1% in 1995 to 17.7% in 2005, and 25% in 2016.

The increase in the internationalization of the Brazilian productive structure is a significant impediment to the local technological and innovative development, since the main technological activities of the subsidiaries of the transnational corporations are reduced to adaptations and improvements of products and processes. Moreover, these companies import many inputs (Cassiolato *et al* 2015).

In Brazil, the opening of the 1990s was expected to motivate innovative and technological efforts by foreign firms, contribute to structural change and reduce the trade deficit by increasing exports. However, most part of the new investments were market seeking, aimed at exploiting the opportunities offered by the domestic market (including Mercosur) and acquiring local companies. There was little new investment. In another paper (Cassiolato and Lastres, 2013), we comment that the technological efforts of transnational corporations in peripheral countries are almost exclusively adaptive. Several studies about Brazil (Cassiolato et al 2014) empirically demonstrate this argument.

Innovation, global system, financializationand role of transnational corporations

After the end of World War II, the Brazilian and Latin American debate on development highlighted the challenge of internalizing the driving forces of the technical progress from a broader and more systemic perspective, not only from the point of view of innovation, economy and global geopolitics. Structuralists, in particular Celso Furtado (1954), pointed out that "many of the most significant manifestations of technical progress can only be fully captured through a global view of the national system, which includes the perception of the relations of this system with the environment by whom it is controlled and influenced".

This scenario presents a major challenge for the least developed countries: the development processes of these countries reflect imitative processes rather than a reflection on internal deficiencies and potentialities. As pointed out by Furtado (1974), transnational corporations obey guidelines that are exempt from the isolated action of any government. He goes on to explain how transnational corporations block the internalization of technical progress and the creation of dynamic centres in the Brazilian productive structure.[10]

Fajnzylber (1989, p.857) summed up this discussion, pointing out that the "empty set"[11] of Latin American economic and social development would be directly linked to the inability to open the black case of technical progress. The origin of this situation would be the very formation of Latin American societies and their institutions, as well as their underdeveloped and colonized cultural context.

In Brazil in the 1990s, the repeated emphasis on transnational corporations led Furtado and other Brazilian structuralists to warn of the distortions in the production and market structure that could arise from the monopoly power of large transnational corporations with the "import of technologies conceived in the leading economies according to a constellation of resources totally different from ours." (Tavares 1972, 50). In Freeman's words, "the indiscriminate importation of technologies developed for completely different environments can have disastrous social and employment effects" (1982, p. 184). Technological dependence is the reason why peripheral countries are generally unable to break with the economic domination to which they are subjected, even with a high degree of diversification.

The negative effects of transnational corporations' subsidiaries become clearer when it is realized that the morphology of these companies and their strategies have changed profoundly in the globalization dominated by finance, which has subordinated them to the logic and to the command of financial capital, shaping new links between finance and industry.

Most of these strategies are based on the centralization of financial assets held by a holding company, most often located in tax havens, outside the reach of legislation and control by the institutions of their original countries. Transnational companies are characterized by a relative decline in the importance attributed to the production activities, increasing the relevance of financial activities and the appropriation of value in intangible assets.Sauviat and Chesnais (2005) discuss the negative effects of these pressures and the tendency to maximize the short-term return on investments, to the detriment of those that impose longer returns (such as education, training and R&D). They point to the predominance of adaptive rather than innovative strategies, warning that such a regime is based on the exploitation of skills accumulated in the past, mainly by public education and research organizations. This jeopardizes the ability to keep on financing and producing knowledge and innovation in the future. Serfati (2008) adds that in most cases, the new strategies try to preserve activities that allow the obtainment of high profit margins, such as business intelligence and design, final product integration, technical assistance and other after-sales services.

Maintaining and expanding the R&D laboratories in the different national spaces allows the transnational company to have greater access to the capabilities and technological routes developed in each national innovation system. Thus, the irradiation of the technological advance follows an inverse direction to the one that supposes the usual argument: when it is the transnational company that holds the main capacities and is organized worldwide, with unique positions of bargaining, it succeeds to absorb the different matrices of knowledge available in the different national innovation systems, not the opposite (Cassiolato, Zucoloto e Tavares, 2014).[12]

In cases in which Brazil stands out, the so-called internationalization of R&D activities refers primarily to the acquisition of local capacities by transnational companies, especially by the acquisition of domestic companies, whose R&D laboratories are "inherited" by the buyers. There are many examples where the operations of these laboratories are reduced or closed (Cassiolato *et al.*, 2001). Thus, the objectives of the developing countries, particularly Brazil, are illusory and misleading in attracting foreign investment in the expectation that it will automatically constitute a pillar of industrial renewal and of an increase in domestic technological capacity. They underestimate the nature and strength of structural factors that significantly modified the strategies and investment priorities of the transnational corporations.

These transformations are consistent with the international division of labour identified by Furtado, now with new characteristics, while maintaining the concentration of knowledge-intensive activities in the central countries, with the less strategic activities located in peripheral countries. In denying the hypothesis of the benefits of the international division of labour based on the neoclassical principle of comparative advantages, Furtado makes clear that the division of labour between centre and periphery maintains and widens the gaps in development and knowledge among nations. Leading countries in more sophisticated products and services preserve their positions, while the less developed ones are restricted to an increasingly obsolete and non-competitive pattern of production and export. Furtado also realized that the process of denationalization and destruction of the productive and innovative endogenous capacity generates a loss of degrees of freedom in politics driving. It increases political and economic subordination to the interests of international financial capital and large multinational conglomerates, creating constraints external to the expansion of exports, the development of the national production and the endogenous capacity to generate knowledge and innovation (Tavares and Fiori, 1997; Fiori, 2001).

At the beginning of the 21st century, the process of international insertion of Brazil and Latin America reproduces the one of the beginning of the 20th century. In this "peripheral reinsertion," our countries specialize in the less complex parts of productive activities. This mainly includes commodities based on large-scale production, low unit price and intensive use of natural and energy resources, produced with simplified technologies and repetitive work. The labour force involved in this productive process costs less and works in more precarious and "flexible" conditions, which do not require high levels of training or knowledge. The main activities in these cases are focused on the execution, distribution and assembly of products.

The peripheral participation in the international trade flows is similar to the one of one century ago. The centre extends the domain of knowledge/creativity-intensive activities, which are strategic and value-generating.

It is necessary to understand the systemic character of the innovation process, associated with economic and technological relations between countries in the context of globalization dominated by finance. Only then it is possible to focus on the insertion of peripheral economies and the role of transnational corporations, making a more appropriate discussion about the reasons behind the failure of the Brazilian innovation policies.

The innovation policy package introduced in Brazil is very similar to that implemented in a big number of developing countries, also with low effectiveness.[13] Different authors point out the role of international financing agencies in guiding and imposing benchmark policy models. Reinert (2016) says that in order to receive support, poor countries must refrain from using the knowledge and policies rich countries have used and still use. He gathered much evidence that orthodox economic policies do not contribute to the development of countries, criticizing the policies of the Washington Consensus and "their slightly modified descendants".

The policy measures adopted in Brazil, despite being guided by a developmental convention, fit into the neoclassical perspective, submitted to the financial logic (Erber, 2011). Other developing countries are characterized by equal subordination, facing similar problems. The low effectiveness of these measures is associated with a narrow and misguided perception of the innovative process and the role and strategies of its main actors.

In addition to disregarding the systemic nature of innovation, these measures overestimate the role of subsidiaries of transnational corporations, considering them as one of the main players in the technological development of host countries. Moreover, they ignore the changes in global production, especially the new strategies of these companies.

Conclusion: innovation policies and development, dilemmas to be deciphered

As commented in this article, the industrial structure installed in the country has not been able to move forward to internalize and improve the productive and innovative capacities, and thereby becoming more capable of contributing to Brazilian development.

> **Innovation is not limited to cutting-edge activities. It applies to all segments, including the most traditional ones, where Brazil has promising job and income generation for the majority of the population.**

There have been undeniable successes in consolidating and expanding the Brazilian education and research infrastructure, particularly with the creation of new federal public universities in regions far from the most important economic centres, and the significant expansion of federal technical schools. But industrial and innovation policy has been unable to meet the challenges brought about by the global reorganization of production and the changes in the strategies of the main agents of the process – the large multinational companies.

Innovation is not limited to cutting-edge activities. It applies to all segments, including the most traditional ones. It is vital to understand it and to extend the innovation policy, especially in countries such as Brazil, with a heterogeneous productive structure, regional inequalities and traditional sectors with great importance in the generation of employment and income. Working with innovation systems requires a fresh look at this process and at the specific reality in focus. It is about building a path of its own rather than seeking a linear catch-up from benchmarks of the experience of developed countries. A path that takes into account the country's history, geopolitics and territorial conditions.

Policies cannot be limited to providing mechanisms and incentives for companies to carry out specific R&D projects. The innovation activities of companies are subordinated to their more general strategies, existent within the productive and innovative systems in which they are inserted. This requires systemic, territorial and focused policies with a long-term perspective, capable of mobilizing cooperative projects that respond to the challenges of industry and society.

We have seen that the Brazilian industrial structure has lost density and quality. Its inter-sectorial linkages have weakened and imported content has increased, especially in the segments of greater technological intensity of higher aggregate value. This is not only due to the limitations of explicit industrial and technological policies. The perverse national macroeconomic environment that values exchange rates, high interest rates and other characteristics has acted as a powerful implicit policy against productive and innovative effort, directly impacting investment decisions, especially those of risk, such as those related to innovation and technological development.

These conclusions highlight the importance of analysing the influence of macroeconomic scenarios and of the political-institutional context of policies to promote development. It is necessary to know how Brazil is inserted in the global geopolitical scenario, the orientation given to the development and the real conditions of implementing any policy, especially for ST&I. The dynamism of our economy is further threatened by the austerity policy and the fiscal adjustment in place since 2015. It is also necessary to take into account the global economic crisis, which began in the United States and has spread and deepened as of 2008.

We reiterate the important legacy of the authors who have helped us to understand the nature of the crises of the world economy and the means to overcome them. The ability of public and private policies to support and reorient the national production and innovation systems must be acknowledged. Freeman (2003, 2007), for example, has always pointed out the relevance of such capacity, particularly in times of ruptures and crises, which he associated with changes in techno-economic paradigms. To resume development in the 21st century, he stressed the need for policies to regulate and renew productive and innovative capacities, observing the imperatives of social inclusion, reduction of inequalities and environmental sustainability. At the beginning of the millennium, when many hailed the advantages of the reduced State and minimum policies, he advocated exactly the opposite: "The active policy agenda is broadened rather than becoming obsolete. This requires deploying even more sophisticated ways to promote industrial and technological development, taking into account local and national conditions, the new pattern of accumulation, and new forms of governance at the global level" (Freeman, 2003).

The current global crisis has economic aspects (low world GDP growth, stagnation of international trade and global demand for most goods and services, low levels of investment), social aspects (increased inequality and poverty) and, above all, politics aspects (threats to the democratic order and the emergence of radicalism from theextreme right). It is exacerbated by the hegemony of austerity policies, added to increased protectionism. All this requires a reflection on the future possibilities of the productive and innovative development in Brazil and of its ST&I policy, which depends on some basic factors. The first and most important one is the establishment of a long-term strategic vision, capable of building consensus and support – that is, the definition of the country project that we want and can implement. The second one refers to the need to visualize an appropriate, cohesive and forward-looking development.

It is urgent to define a national development project that is inclusive, cohesive and forward-looking, able to recover the long-term planning and the ability of considering the heterogeneity and specificity of the Brazilian social and economic structures.

The perverse macroeconomic environment – whereby priority is placed on exchange rates and high interest rates – impacts investment decisions and hampers the greater innovative effort that the Brazilian economy needs to make.

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In spite of the rhetoric about the systemic dimension of innovation, the Brazilian ST&I policy has supported the university's approach to the productive sector and support for R&D through fiscal and credit incentives in recent decades. Focusing only on the treatment of market failures, this concept was disseminated at an international level, with few expressive results (Cassiolato e Lastres, 2011).

For the success of the policy, it is necessary not to mimic the agendas of the countries considered to be more developed. The contextualization of politics must be placed at the centre of the debate, adapting it to the specificities of the Brazilian society and economy and its development objectives.

The contextualization of politics means to prioritize the main problems of our economy and society, seeking to converge the productive development and actions with the social impact. In addition to the tendency to copying models, agendas and policy instruments generated in other contexts, with no adjustments, we have decoupled the goals of ST&I (and industrial) policy and the needs of the social development. Demands for health, education, housing, transportation, sanitation and culture, among others, are intensive in productive and innovative qualification and in new technologies that cannot be imported. They are specific to the different territories.

The agenda needs to keep the social dimension at the centre of its concerns by mobilizing and consolidating the new educational and technological research structures, focusing on local problems such as federal institutes, new regional public universities and technological vocational centres. These institutions are already being used in an incipient way in the technological training and in the diffusion of S&T knowledge, with a view to improving the local productive arrangements, but this concern is still low.

A great opportunity would be to stimulate the development of productive and innovative arrangements aimed at increasing the quality and provision of essential public services. The policy should be geared mainly to mobilize and strengthen capacities, activities and productive and innovative systems to provide food, health, education, housing (with sanitation and access to water and energy), solid waste treatment, and culture, among others public services.

In addition to promoting greater integration and strengthening of development policy, ST&I policies must advance in the exploitation of the territorial dimension. So far, they still incorporate an outdated view, from the spatial point of view. They still put the regional question only as a compensatory appendix. The sectorial approach is still devised in a de-territorialized way.

Finally, Brazil should take advantage of the opportunities arising from the exhaustion of the productive paradigm based on mass production and consumption, intensive in the exploitation of non-renewable natural resources. Given our specificities, the potential of the new paradigm that revolves around sustainability is significant. It is necessary to choose priorities that relate to the great challenges of the Brazilian society. The selection of sectors considered as "strategic" or "bearers of the future" should prioritize the ones with the greatest impact on our economy and society. Besides opening new and adequate spaces for Brazilian development, such proposals have the potential to solve some of their most serious distortions and more pressing threats: deindustrialization and increasing imports of manufactured goods, technologies and other goods and services.

Such a strategy can contribute to reverse the logic that has prevailed in the Brazilian development, unveiling, mobilizing and rooting future-bearing potential. This path is far from trivial. However, it is one among several possibilities considered by Celso Furtado, his colleagues and followers for a long time: advance in the understanding of the dilemmas placed for our development and to persevere in deciphering of ways to reach the goal. It is agenda on which the role of foreign capital would be, at most, marginal. ▪

Notes

1. See Cassiolato, 2001.
2. The three main sources of funding for public science and technology institutions - the FNDCT and the budgets of CNPq and CAPES - received in 1985 only 40% of the amount allocated to them in 1979 (Bielchowsky, 1985).
3. Coutinho, 2005.
4. Cassiolato, 1992; Cassiolato and Lastres, 2016; Castro et al., 2017.
5. Unfortunately, at the beginning of the second decade of the millennium, an agenda that emphasized state purchasing power as an important innovation policy mechanismwas barely introduced. A small positive result was achieved, especially in the health area, but the experiment was abandoned in 2016.
6. On what we call the invisible exclusion by concepts and policy models restrictive by definition, see Lastres and Cassiolato, 2017.
7. 2000-2015 data from Pintec, regarding the subsidiaries of transnational corporations with more than 500 employees in technology-intensive sectors, demonstrating the dramatic nature of the situation. In the activities that received the most tax and credit incentives (automobile, pharmaceutical, communications equipment, chemical and machinery and equipment industries), transnational corporations, in fact, significantly decreased their expenditures with innovation in Brazil (Cassiolato e Lastres 2016 e Cassiolato, Szapiro e Lastres 2015).
8. IBGE data. As a comparison, between 2008 and 2010, in the USA, the weight of ICT in general GDP was approximately 9% and in the European Union it varied between 5% and 7% (Cassiolato et al., 2015). The emptying of the productive and innovative systems of the electronic complex (communications and computer equipment) can be noticed with the observation that, as of 2008, approximately 70% of the final Brazilian demand for these products was supplied by imports. The national industry already differed "very little from a typical make-up industry" (Morceiro, 2012, p. 190).
9. https://www.bcb.gov.br/Rex/CensoCE/port/resultados_censos.asp?idpai=CAMBIO
10. Furtado, 1981. In his 1954 book, Furtado already claimed that the remuneration of foreign investments meant a resource leak that limited the possibility of local reinvestment. The inflow of foreign capital, even in periods of great influx (1925-1929), was not sufficient to compensate for the services of the corresponding capital, in addition to aggravating the problem of external vulnerability, limiting the possible investment rate.
11. The empty set expression refers to a matrix which vertical reference means growth and the horizontal means income distribution. In Latin America, there are no countries that were dynamic and had a good income distribution at the same time: this is the empty set in this region.
12. Although a specific national innovation system is not articulated in such a way as to generate an innovative (and therefore productive) dynamic, it will almost always have specific capabilities and complementary assets useful to the global transnational strategy.
13. Scerri and Lastres (2013) and Cassiolato and Vitorino (2010) present evidences in this direction for the innovation policy of Brazil, Russia and South Africa. Kahn, Melo and Matos (2014) show, for the same countries, the shortcomings and lack of financial mechanisms to support innovation.

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The Brazilian energy matrix to the 2050 horizon

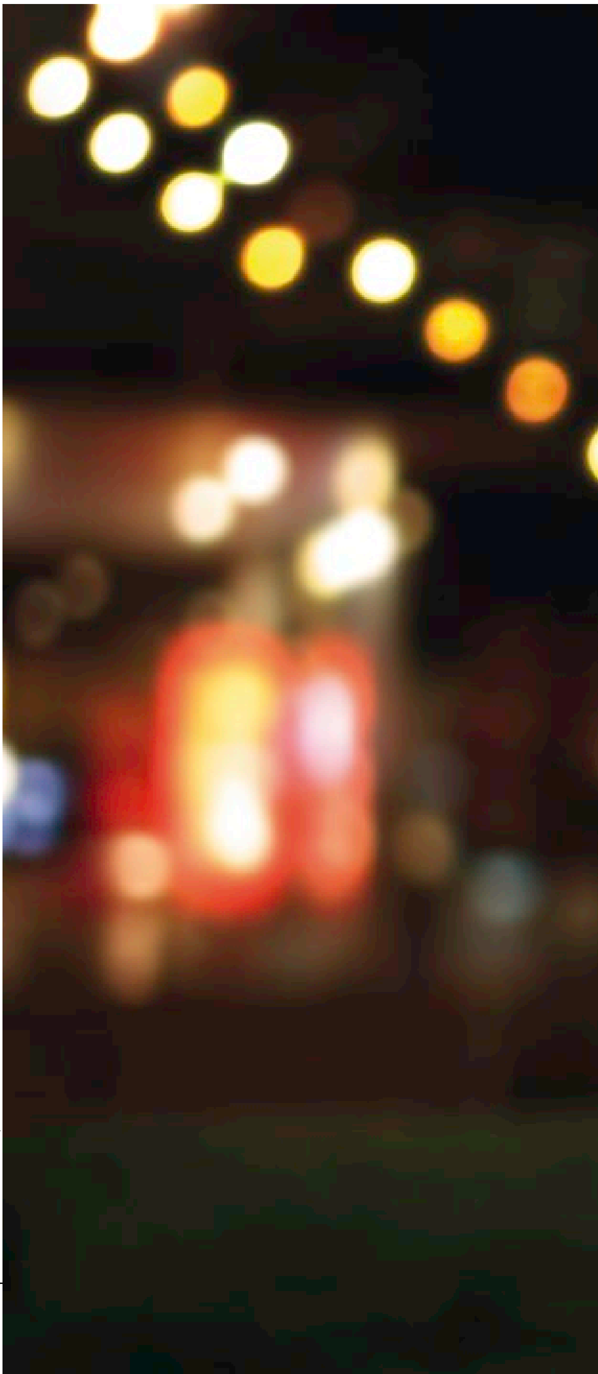
The Brazilian energy reserves ensure our self-sufficiency. On the horizon of non-renewable sources already studied, Brazil has reserves of more than 20 billion tonnes of oil equivalent (toe) to meet an annual demand of 600 million toe by 2050. In other words, the reserves of these sources can meet the demand for more than thirty years. Even more surprising is that Brazil has potential renewable sources of more than 7 billion toe, almost ten times our demand in 2050.

According to the 2017 National Energy Balance (*BEN* 2018), published by the Energy Research Company (*EPE*) of the Ministry of Mines and Energy, the domestic energy supply was 293.5 million toe, for a consumption of 260.0 million toe, with a loss of 33.5 million toe. Brazil also stood out in 2017 for the quality of this offer, with 43.2% of renewable sources, when the world average is 13.7%. In 2017, the main renewable sources were biomass of cane (17.4%), hydraulic (11.9%), firewood and charcoal (8.0%), black liquor and others (5.8%).

Presently, EPE prepares studies and coordinates debates to build the new energy matrix, having as a horizon the year 2050 and calling it the National Energy Plan (*PEN 2050*). Available studies indicate that in the current year Brazil will demand about 600 million toe in energy.

The recently released technical note PR 04/18 of the EPE– Energy Resources Potential 2050 – brings important technical information about our energy matrix. In addition, it offers elements to define strategies and public policies for the exploitation of the matrixin order to guarantee energy security in the first half of the 21st century. It also offers the means to increase the use of these energy resources with minimal harm to the environment.

This paper aims to offer a synthesis of the study provided by EPE through NT 04/18. The energy balance in the 2050 horizon, made by EPE, is shown in Figure 1.



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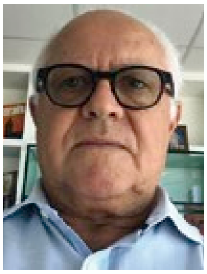

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Engineer, former president of the São Francisco Hydroelectric Company, former Secretary of Infrastructure of Pernambuco and consultant.

Brazil has large-scale energy resources that are more than enough to meet the needs of society in the long term. Our development strategy should focus on renewable sources. The Northeast region can become a major energy supplier for the whole country, due to its winds, sunshine, and 3,000km of coastline for the construction of offshore plants. It houses the largest reserves of uranium, produces a lot of biomass and has area suitable for planting energy forests.

From the point of view of domestic supply, the energy matrix synthesized in Figure 1 places Brazil at a comfortable level in the next thirty years. Considering domestic demand estimated at 600 million toe by 2050, Brazilian needs could be met only with potentially available non-renewable resources. Most important: the estimated renewable resources are ten times higher than our needs. The challenge to governments and society is to maximize the use of renewable energy sources to meet our energy needs, increasingly avoiding the use of polluting sources.

Brazil was a pioneer in the substitution of petroleum derivatives for sugarcane alcohol in the late 1990s. At the time, the *Pro-álcool* program showed the world an important way to reduce the effects of greenhouse gas emissions, mainly in the transportation of people and goods. The automobile industry was modernized and produced a line of flex-fuel vehicles, now predominant on the market. The Brazilian Solid Waste Law in force since 2010 suggests the use of biomass of urban waste in energy generation. Although still in its beginnings, energy forestryis already present in Brazil; and wind and solar power has begun to occupy an important space in our matrix. Unfortunately, the country lacks the definition of an integrated long-term strategy for the use of our abundant energy resources. This will require a broad debate, capable of producing a social consensus that reconciles commitments to economic and social development on the one hand and environmental sustainability on the other, based knowledge of our own energy wealth.

Brazil intensified inventory studies of its energy resources in the second half of the 20th century after creating Petrobras and Eletrobras, coordinated by the Ministry of Mines and Energy, which also prospected for mineral resources. Universities played a decisive role in supporting the development of these studies.

At the turn to the 21st century, Brazil institutionalized more robust energy planning with the creation of the National Energy Policy Council (*CNPE*, August 1997) and the Energy Research Company (*EPE*, March 2004). In 2007, EPE prepared *PNE-2030*, its first integrated energy plan with a long-term view, marking the resumption of the national

Figure 1 | Brazilian energy potential (millions of Tep)

	SOURCE	2015 - 2050		SOURCE	2015 - 2050
Renewable	Biomass	531	Non-renewable	Oil	9.047
	Hydraulic	74		Natural gas	2.926
	Onshore Wind	30		Mineral coal	7.157
	Offshore Wind	1.356		Uranium	2.411
	PV Onshore	43		**SUB-TOTAL 1**	**21.541**
	Hydrothermal	57	**Estimated demand in 2050 = 600 Mtep**		
	PV Offshre	5.247			
	Oceanic	34			
	SUB-TOTAL 2	**7.372**			

Remarks: (1) It includes conventional, discovered, contingent and undiscovered resources. (2) Includes both discovered and undiscovered conventional resources and non-conventional resources. (3) It considers total reserves, with an average recovery of 77% and heat capacity of 3,900 kcal / kg. (4) It considers total reserves and losses of mining and beneficiation. (5) It considers areas with irradiation range of 6.0 to 6.2 kwh/m^2. (6) It considers areas with radiation range of 6.5 to 6.8 kwh / m^2.

Biomass, rivers, winds, sunshine, oil, natural gas, uranium and coal are the main components of a diverse and very generous energy matrix.

energy planning. It was the most important government study of integrated energy planning. Since then, the data provided by PNE-2030 have been an important reference in the elaboration of scenarios for long-term economic-energy studies. They have been used in the various governmental areas and in energy studies produced by the most diverse sectors of society. The first government guidelines were born with solid fundamentals to prioritize the use of Brazilian energy resources.

The plan highlighted the strategic importance of nuclear energy; placed hydro-electricity as a priority source for electric power generation; increased the importance of natural gas and ethanol in the composition of the energy matrix; and highlighted the high potential for oil and natural gas production in Brazilian land and water areas.

Between 2007 and today there have been changes: fossil energy prices returned to great volatility; society has imposed severe restrictions on the use of hydro-electricity (mainly in the Amazon, where there is great unexplored potential); there have been nuclear accidents around the whole world; wind and solar energy have become cheaper and economically viable; and non-conventional fossil fuels began to be intensively exploited in the United States. Such events have shown that energy planning is an obligatory instrument for the strategic orientation of any nation. It is indispensable to know our energy resources to use them properly and to preserve them.

Our energy matrix

Recently, EPE published the Technical Note PR 04/2018, a reference for the preparation of the PNE 2050. In the introduction, the EPE draws attention to the fact that, although we have enough resources for self-sufficiency in energy and exportation of oil, we still import electricity and fuels.

THE RENEWABLE MATRIX

BIOMASS

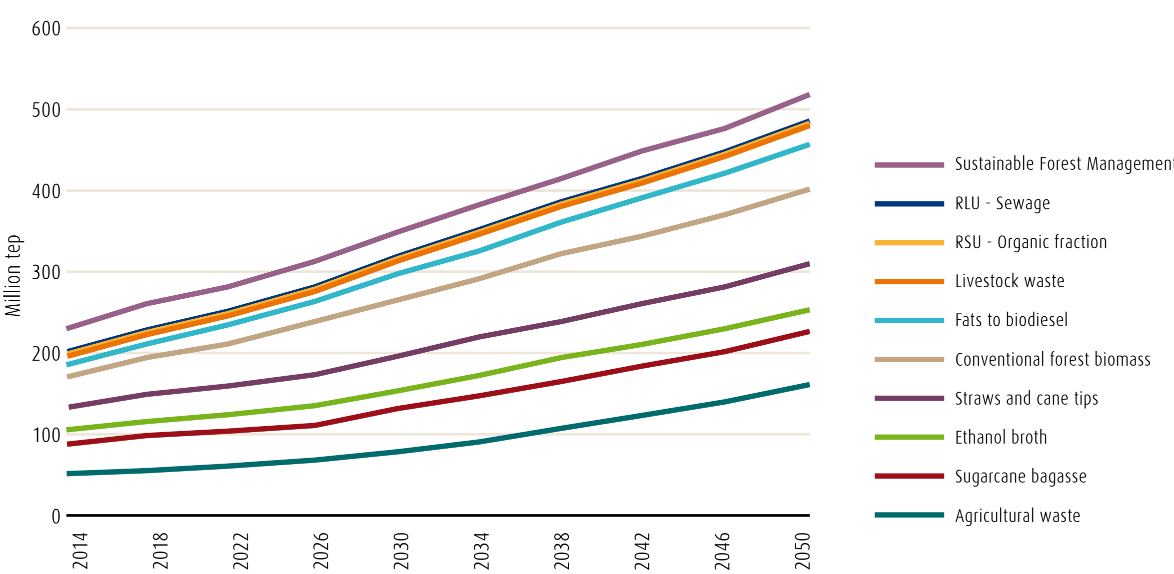
This is one of the great Brazilian treasures. Bioenergy is expected to reach over 500 million toe, or about 8% of global bioenergy, within the plan horizon. Its use has been growing rapidly. In the EPE proposition, it recognized that bioenergy plays a key role in rural development, in addition to contributing to the improvement of the environmental quality of the energy matrix. In 2014, according to the National Energy Balance, bioenergy accounted for 25.6% of the domestic energy supply. Cane products contributed with 15.7%, firewood and charcoal products with 8.1% and black liquor with 1.8%.

Brazil can produce biomass throughout its immense territory. The country has very favourable climatic conditions, dominates with competitive production technology, and has an abundant market. In addition, it has instituted national policies that require treatment and proper disposal of waste. The precarious infrastructure of logistics, predominantly road transportation, makes it difficult to expand production and use of bioenergy.

Despite the high degree of technological knowledge and operational capacity to produce biomass from sugarcane and forests, Brazil has an immense amount of biomass not yet adequately exploited, especially agricultural residues (such as straw and sugarcane tips), biodiesel fats, livestock waste, organic residue from urban waste, liquid waste from sewage treatment and biomass from forest management.

For the energy plan, the EPE studied the areas available to produce biomass in detail, including the costs in each one of them and strictly respecting restricted areas, such as indigenous and *quilombola* lands, conservation/preservation/legal reserve areas, urban areas, wetlands and the legal Amazon, among others. The result of the study pointed to a potential area of 144 million hectares for expansion of the agricultural frontier. Much of it already presents anthropic use, classified as livestock or farming, or is cov-

Figure 2 | Evolution of bioenergy potential in the long term



Source: EPE

ered by native vegetation. The guidelines aimed at enhancing the use of biomass energy represent a valuable roadmap for the formulation of public policies in this area.

The definition of policies to expand and exploit the energy source of biomass, which is essential for building a clean matrix, should examine the complex interdependence with other sectors, such as the environment, agriculture and livestock, food safety, land use, technological development and capacity of financing, among others. In addition to being very important by itself, increasing the share of bioenergy in our matrix is also generating a lot of less qualified manpower. The forecasts of the EPE study can be seen in Figure 2.

It is worth mentioning the EPE conclusions on bioenergy: "By 2050, the biomass potential will be 530 million toe. In the year, agricultural biomass will be able to contribute with about 165 million toe, representing the main source with potential for bioenergy supply. Together, sugar cane products – pulp, cane juice for ethanol, straw and tips – are in second place and should account for 152 million toe. In addition, there are the 17 million toe of biodiesel produced from palm oil in the Amazon biome, not represented in the figure. Fats for biodiesel have an energy potential of 56 million toe. And the forest biomass and livestock waste (used as biogas) could contribute with 95 million toe and 28 million toe, respectively. Sustainable forest management has a potential of 32 million toe."

"Brazil already has a leading position worldwide in terms of renewability of the energy matrix. The projection of biomass potential for energy purposes indicates there is potentiality to move forward."

"The development of biomass-based energy chains can significantly increase the supply of renewable energy through various energy sources such as biogas, biomethane and firewood for electricity generation. Moreover, since most of the potential resides in two large groups, the sugar and alcohol industry and the residual biomass, the development of this potential presents interesting competitive advantages. In the case of the sugar and alcohol industry, the main advantage is the production park and the already established markets. In the case of residual biomass, the advantage is in increasing economic productivity, since there is value generation from waste, as well as mitigation of local and regional environmental impacts."

THE RENEWABLE MATRIX

WATER RESOURCES

Hydro-electricity accounted for 16.6% of world energy production in 2014. Brazil, the second largest country in installed capacity (89 GW), accounts for 8.6% of installed capacity worldwide. Besides being a clean, renewable and low-cost source, hydro-electric plants operate in a very flexible way and their reservoirs play an important role in the regulation of downstream flows. They also present other important externalities to the power generation project. However, the increasingly demanded, multiple-use of water by society has imposed operating restrictions, especially in the last decadewhen there have been successive bad hydrological cycles.

Brazil still has great hydroelectric potential to exploit, but they are located predominantly in the Amazon region. It is for this reason that society resists to the expansion of the use of hydro-electricity in the matrix. Even choosing run-of-river reservoirs with little deforestation, there are still areas of environmental preservation. The difficulties to implement new projects are increasing, not to mention the need to build thousands of kilometres of transmission lines to cross those Amazonian areas. For this reason, the selection of new hydro-electric power plant projects will have to reconcile deployment costs, energy benefits and socio-environmental impacts.

The decision to build the Belo Monte plant provoked a great reaction in Brazil and abroad. The government had to review the initial project, significantly reducing the reservoir and, in the same proportion, the quantity of energy. Later, when detailed studies of using the Tapajós River began, new outbreaks of resistance resulted in major delays in the projects. Although this has not been made explicit, the entities responsible for energy planning increasingly moved away from the hydro-electric alternative in the Amazon region, where almost all the untapped potential is found. New arrangements are sought to take advantage of this potential, for example, by avoiding reservoirs construction and by implanting state-of-the-art reversible plants.

Even in the face of such restrictions, the EPE included the Brazilian hydro-electric potential in the energy matrix in PNE 2050, since it was inevitable.

According to an Eletrobras report of 1994, the estimated hydro-electric potential was 261.4 GW, of which 61 GW was already in operation and 10 GW were allocated to high-end plants. 98 GW were already inventoried and 102 GW was an estimated value.

In PNE 2030 (Brazil, 2007b), the potential capacity of 251 GW consisted of the capacity harnessed until then (78 GW), with an inventoried capacity (126 GW) and by an estimated potential capacity (47 GW). After the publication of PNE 2030, part of the inventory potential was built or is under construction and part of the estimated potential was the subject of inventory studies. New inventories were performed and others were reviewed, increasing the accuracy and reliability of the hydro-electric potential.

After the PNE 2030 was published, the hydro-electric inventories of the rivers Aripuanã, Araguaia, Branco, Jari, Juruena and Sucunduri, some of the largest Brazilian rivers, were carried out by EPE and approved by Aneel, which brought greater reliability to the estimates. The potential values to be incorporated into the PNE 2050 only considered the data collection of the installed capacity of the hydroelectric plants, including those with a power of less than 30MW, not considering the estimated poten-

Between 2001 and 2017, the installed capacity of wind power plants in the world increased from 23.9 GW to 539.6 GW. Such equipment also works offshore on the surface of the oceans, extending its range of action.

tial capacity ("Monitoring report of studies and projects of hydro-electric power plants. Scenario of 14/07/2017", Aneel, 2017). The result of the data collection indicated a hydro-electric potential capacity of 176 GW, 108 GW in operation and construction and 68 GW in inventory (Figure 3).

Figure 3 | The Brazilian hydroelectric potential

Stage	Plant Hydroelectric (GW)	UHE P<30MW (GW)	Total (GW)	Participation (%)
In Operation and Construction	102	6	108	61.36%
Potential Hid. Inventory	52	16	68	38.64%
Brazilian Hydroelectric Potential	154	22	176	100%

Source: EPE. Remarks: (1) It is considered only 50% of the power of Itaipu (binational plant). (2) From the total of 52 GW of potential UHEs, about 12 GW do not present interference in the protected areas (conservation units, indigenous lands and quilombola territories).

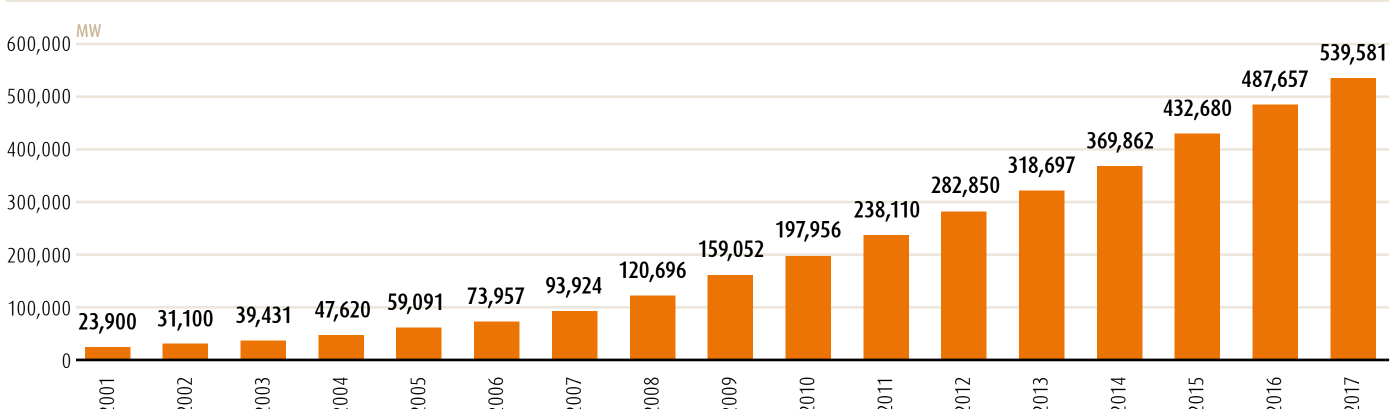
THE RENEWABLE MATRIX
WIND ENERGY

The use of wind power to generate large-scale electricity began at the end of the twentieth century, either by technological advances or mainly by government incentives to reduce greenhouse gas emissions and other environmental concerns. According to GEWC (2018), the countries that have stood out the most in the implementation of wind power plants are China (35%), the United States (17%) and Germany (10%). Between 2001 and 2017 the installed capacity of wind power plants in the world jumped from 23.9 GW to 539.6 GW – or 22 times greater. Almost all of this potential is on land, but facilities at sea are growing rapidly.

Despite the rapid growth, wind energy accounted for only 4% of the world's generated energy in 2016 (Figure 4).

The first inventories of wind energy in Brazil were made by Eletrobras and published in 1979/1980, noticing the great potential in the coastal and rural areas. In 2001 a new Atlas of the Brazilian wind potential was developed (Amarante, 2001), this time with better measurement resources, using modern computational methods. Although still limited if compared to current techniques, the inventory at the timehad already shown 143 GW of potential installed wind capacity in Brazil. Soon technological advances made it possible to build wind turbines with 100 meters in height, while the Brazilian Atlas had been made with average of 50 meters. Therefore, it could already be ensured that the wind potential

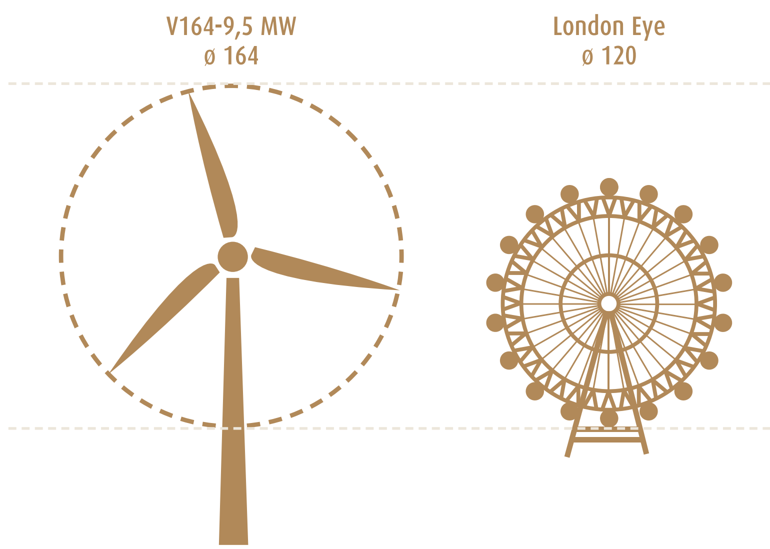
Figure 4 | Evolution of installed wind power in the world



Source: GWEC (2018).

Pioneering countries have already withdrawn subsidies for solar energy, since it has consolidated as a market and its prices have fallen sharply.

Figure 5 | Wind turbine V164, with 9.5 MW



would be well above the 143 GW originally estimated.

The participation of wind power on a larger scale in the National Interconnected System (SIN) still faces operational problems, such as intermittency, infrastructure problems and environmental restrictions in protected areas.

In addition to the onshore built-up areas, offshore construction in the world is advancing with 18 GW installed capacity and wind turbines up to 12MW each, as well as blade rotors 220 meters in diameter. The largest wind turbine in operation in the world has a rotor with a diameter nearly twice the diameter of the London Eye (Figure 5).

Brazil is still starting the exploitation of offshore wind farms, but it is already known that the potential of this source at sea is extraordinary. According to a study by Ortiz and Kampel (2011), it can vary between 57 GW and 1,780 GW.

The Brazilian operational experience with wind farms is still incipient (five years old), but results have already shown that Brazil, especially the Northeast region, is the place where wind turbines have the best operating performances in the world. In addition, Brazil has an excellent hydro-electric generation base, which is very efficient in regulating an electrical system with a strong presence of intermittent sources, such as wind.

We still do not know how much wind capacity we can insert in the SIN. The accumulated experience and the complementarity of the solar and wind sources show a very promising future. The final balance presented by EPE indicates a potential for the installation of approximately 60 GW of onshore wind and 2,700 GW on the Brazilian seas, a much higher potential than that of the hydro-electric source.

THE RENEWABLE MATRIX

SOLAR ENERGY

About half of the incoming energy from the Sun reaches the surface of the Earth, totalling about 885 million TWh/year, more than 8,500 times the total final energy consumption in the world (IEA, 2011). These values give the solar source, considering its multiple uses, the greatest technical potential of use if compared to other renewable sources (IPCC, 2011).

The studies elaborated by EPE for PNE 2050 considered the applications derived from two main ways of capturing the energy of the Sun, through heat and the photovoltaic effect. Both allow this energy to be used for heating and cooling environments, water heating, photovoltaic electricity generation and heliothermic generation.

The use of this source, especially the photovoltaic application, grew 44% in the world between 2004 and 2016, reaching 303 GW (REN 21, 2017), thanks to generous subsidies granted by European countries. As the technology spread, the pioneer countries withdrew the subsidies, since it was consolidated and prices had fallen, especially in Asia. Only in water heating systems there was an installed capacity of 456 GWh in 2016 (REN21, 2017).

The geographical position of Brazil provides high rates of solar radiation throughout the country, including winter. Here, the average irradiation varies from 4,000 to 6,200 kWh/ m², which makes the Brazilian territory one of the most promising for the use of this kind of resource.

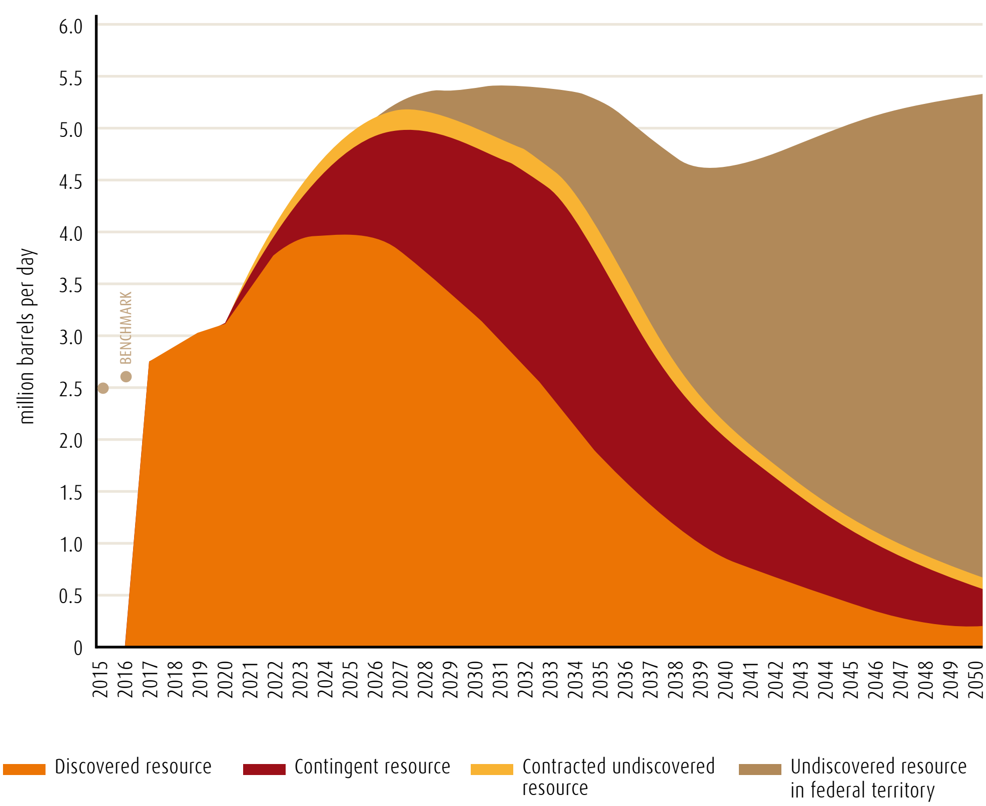
The studies elaborated by the EPE excluded areas of the Amazon and Pantanal biomes, lands with a slope of more than 3% and dimensions of less than 0.5 km², and all the indigenous and *quilombola* areas, as well as the Atlantic Forest with native vegetation, urban areas and rivers. Furthermore, the EPE even reduced the study area by 20% to meet other legal restrictions. As a result, an area of 960,072km² was identified as capable of implementing photovoltaic systems.

Considering only the anthropogenic areas (around 400,000km²) and irradiating between 6,000 and 6,200Wh year, the EPE estimated the potential for generating solar power at 307GW at the peak and 506TWh per year. As areas with lower irradiance are also very conducive to the deployment of photovoltaic plants, the abovementioned potential is only an indication, since it may be up to twice as large. Even with such restrictions, Brazil has a potential ten times greater than the installed power in Germany until 2014. Compared to the generation capacity of all the sources already implanted in Brazil (about 120GW), the solar potential (onshore) represents the triple of the generation capacity.

What has still not been considered is the possibility of using distributed generation,whereby consumersinstall solar generators in or near their residence. Aneel regulated this possibility through Resolution 482/2012, calling it distributed generation. To date, about 40,000 micro- and mini-generators have already been installed in Brazil, and it is expected that they will be 1.2 million by 2024.

Recent studies, developed by EPE/GIZ, showed that available residential areas would be sufficient to produce energy in distributed form to supply the equivalent of 2.3 times the residential consumption of Brazil for the horizon of the 2050 Plan.

Figure 6 | Projections of conventional daily oil production in Brazil



Million barrels per day	2020	2030	2040	2050
Discovered resource	3.108	3.223	.920	.263
Contingent resource	.009	1.592	1.152	.392
Contracted undiscovered resource	.004	.179	.147	.080
Undiscovered resource in federal territory	0	.391	2.483	4.561
Total	**3.121**	**5.385**	**4.702**	**5.296**

Source: adapted from data provided by the EPE.

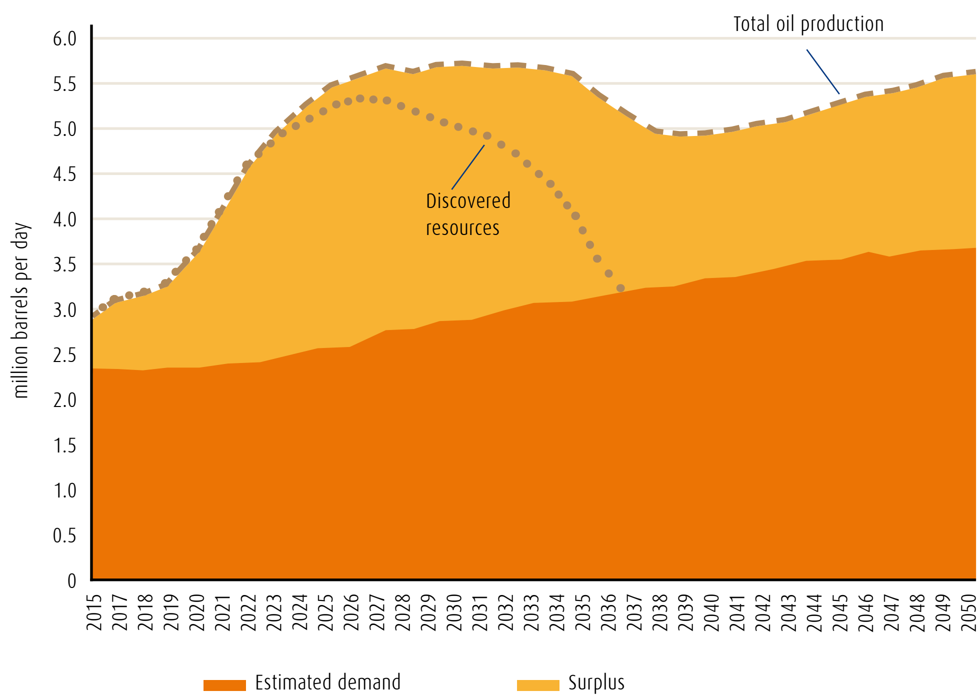
Currently, the distributed photovoltaic power supplies only 0.45% of Brazil's residential load, estimated at 134,000GWh/year. That means that about 80,000MW would have to be installed to meet the whole residential consumption. There is enough space to supply twice as much. The growth potential of this alternative is fantastic.

The government has recently released a credit line of R$ 2 billion for individuals via BNDES. This will greatly boost distributed generation.

In addition to this enormous land potential, the Brazilian coastline has spectacular potential. The data is still scant, but the EPE estimated a possibility of installing more than 5,000GW of capacity, producing energy of up to 94,000TWh/year.

Another application to take advantage of solar energy are the heliothermic plants. They are not as modular as photovoltaics and require the presence of infrastructure, the availability of land at acceptable costs, and proximity to the load centres, among other factors. Using as reference the work of Burgi (2013), the EPE estimated that the potential for building heliothermic plants in Brazil can range from 90GW to 400GW, depending on the chosen technology – the parabolic cylinder or the solar tower.

Figure 7 | Estimates of demand and surplus of conventional oil production in Brazil until 2050



Million barrels per day	2020	2030	2040	2050
Estimated demand	2.240	2.750	3.190	3.550
Surplus	.881	2.635	1.152	1.746
Total	**3.121**	**5.385**	**4.702**	**5.296**

Source: adapted from data provided by the EPE.

NON-RENEWABLE MATRIX

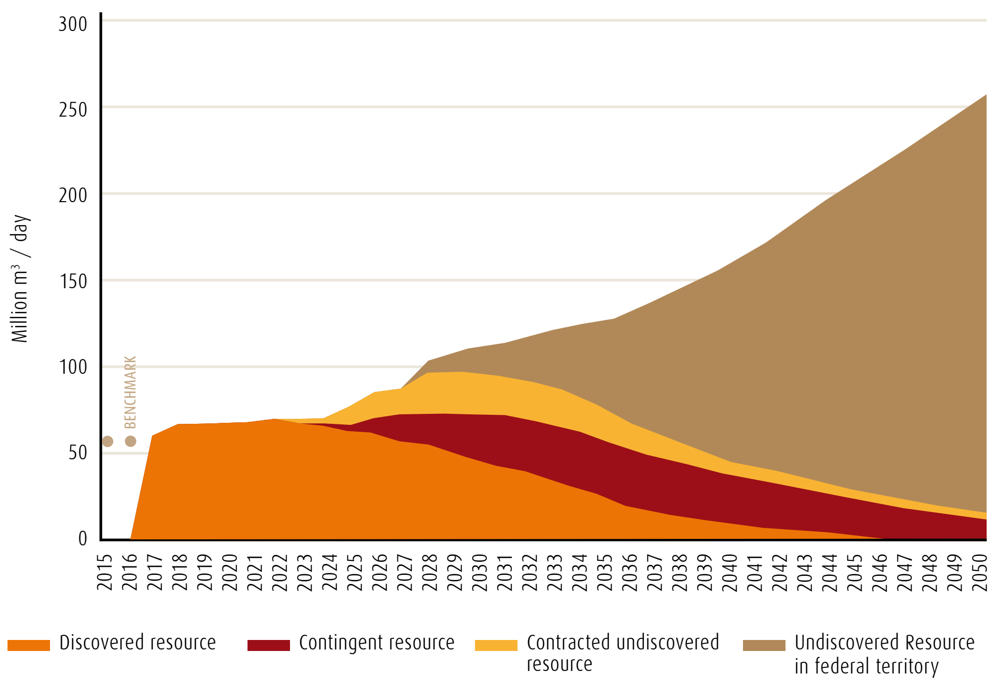
OIL AND NATURAL GAS

Soon Brazil will join the club of the world's largest oil producers. EPE's expectation is that we will have more oil than needed for our future consumption, which is expected to grow more than 50% over current consumption. Even with this comfortable forecast, we should not seek to expand our consumption, since, as we have seen, there is enough renewable energy for the Brazilian needs.

The Technical Note indicates proven world reserves of 1.7 trillion barrels, with 70% in OPEC countries. In Brazil, proven oil reserves reached about 13 billion barrels, or 0.7% of world reserves. Our natural gas reserves reached 0.4 trillion cubic meters, or 0.2% of world reserves.

Based on the discoveries and production of 2016, Brazilian reserves would meet our oil production for fifteen years and the gas production for eleven years. If potential reserves were considered, Brazil would have sufficient oil reserves for 27 years and natural gas production for 21 years at the levels of demand. By 2050 the daily production of petroleum should reach double the current one, as shown in Figure 6. With this level of production, Brazil will have a significant available export volume, as shown in Figure 7.

Figure 8 | Daily production estimates – natural gas (net potential) in Brazil by 2050



Million m^3 per day	2020	2030	2040	2050
Discovered resource	68.1	47.6	11.3	2.2
Contingent resource	0.1	24.4	27.4	13.1
Contracted undiscovered resource	0.1	25.6	9.3	2.3
Undiscovered Resource in federal territory	0	17.2	108.8	238.7
Total	**68.3**	**114.8**	**156.8**	**256.3**

Source: adapted from data provided by the EPE.

We can also become a major producer of natural gas, a welcome source from the environmental point of view, when compared to other fossil fuels. The challenge is to increase gas production regardless of oil production in order to allow autonomous strategies for its usage, which is different from the current scenario. The EPE emphasizes that "[i]t is worth highlighting the huge areas with potential new discoveries of non-associated natural gas accumulations, such as the ones in the basins of Acre-Madre de Dios, Seal, Solimões, Amazonas, Parnaíba and Paraná."

Decennial plans should point out ways to discourage the consumption of petroleum by-products (heavy oils, diesel, gasoline etc.), so that they are increasingly replaced by natural gas. In the Brazilian territory there are large areas with potential exploitation of non-oil associated gas.

As Figure 8 shows, if we consider the resources not yet discovered our natural gas production could be up to five times higher than the current one. It is important for the country to move in this direction. If we employ gas-fired power plants at the base, that is, 24 hours a day, this would create a robust market for gas, allowing the elimination of heavy-fuel or diesel fuelled thermal plants.

In assessing the energy resources of oil and gas sources, the EPE did not include the exploitation of the so-called non-conventional sources. The United States started to exploit these resources to the point of unbalancing the world market, but the Brazilian authorities believe that it is too early to follow this path, since the environmental risks are very high. Although it was a good decision, it does not mean this question cannot be revisited, especially if there is a technology upgrade that merits it.

Oil and conventional natural gas are abundant in Brazil. The great challenge is to exploit these resources with minimal environmental impact. In their study, the EPE concluded that production expectations and the oil and by-products demand will not be significantly reduced even when

Brazil must develop competencies in all stages of the nuclear industry, including the manufacturing of equipment.

introducing socio-environmental constraints. This issue must be further elaborated for the plan.

According to the EPE, the socio-environmental criteria adopted incorporates the guidelines of the environmental and regulatory agencies, besides discarding areas of high environmental sensitivity, such as conservation units; areas for environmental protection and sustainable development; indigenous lands and areas occupied by remnants of *quilombos*; urban areas; and areas of marine life, such as manatees, porpoises and Bryde's whales.

Even so, society must revisit the guidelines of these environmental agencies, especially those of IBAMA for conservation units and their buffer zones; indigenous lands and priority areas for conservation, sustainable use and sharing the benefits of Brazilian biodiversity.

NON-RENEWABLE MATRIX

URANIUM

Uranium is a very important energy generator for the world, despite the risks inherent in its use. So far there have been few accidents at facilities that use uranium as an energy generator, but the consequences in all cases have been very serious. Therefore, the incorporation of nuclear energy in the world energy matrix is controversial. The most intensive use of this energy source is the generation of electric energy. In the world, there are currently about 375,000MW (World Energy Outlook) produced by nuclear reactors in operation. This represents more than three times the capacity of the electric power generation implemented in Brazil.

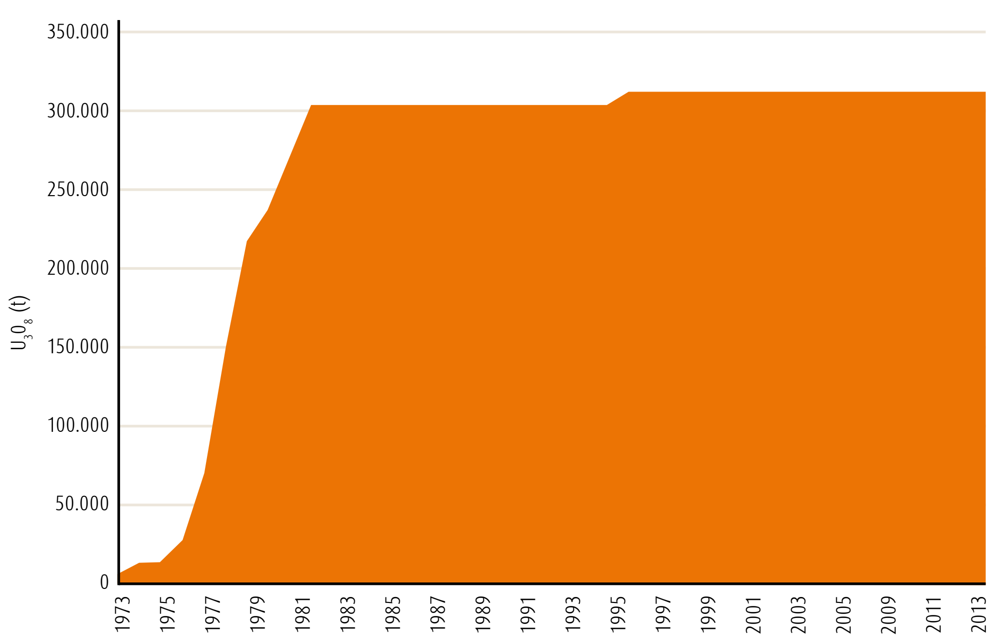
The debate is about whether or not this source should be used for electricity generation in Brazil, a country that holds about 5% of the world's uranium reserves and is the fourteenth in the world production. In the joint strategic guidelines of the Ministries of Environment, Mines and Energy, Development, Industry and Commerce, Science, Technology and Innovation and Defence, inserted in the Brazilian Nuclear Program, Brazil must consolidate itself as an important manufacturer of nuclear fuel, in order to develop competence in all stages, from the manufacturing of equipment to the production of fuel elements, through Nuclebras. The plan establishes a great effort to strengthen regulation of this sector in Brazil.

Brazil belongs to the select group of countries (including the United States and Russia) that dominates the entire fuel cycle and has reserves to meet its own demand. Our first multipurpose reactor is expected to come online in the coming months, with a capacity of 30MW. The Ministry of Defence approved the National Defence Strategy, considering cyberspace, aerospace and the nuclear sector as crucial to the strategic need dominate such technology and ratify Brazil's adhesion to the Treaty on the Non-Proliferation of Nuclear Weapons.

Uranium must therefore be considered in our energy matrix, so that we can advance in the areas of agriculture, health, power generation and nuclear propulsion, among others.

As shown in Figure 9, Brazil developed research in only 25% of its territory and identified re-

Figure 9 | Evolution of the Brazilian uranium reserves (tons of U_3O_8)

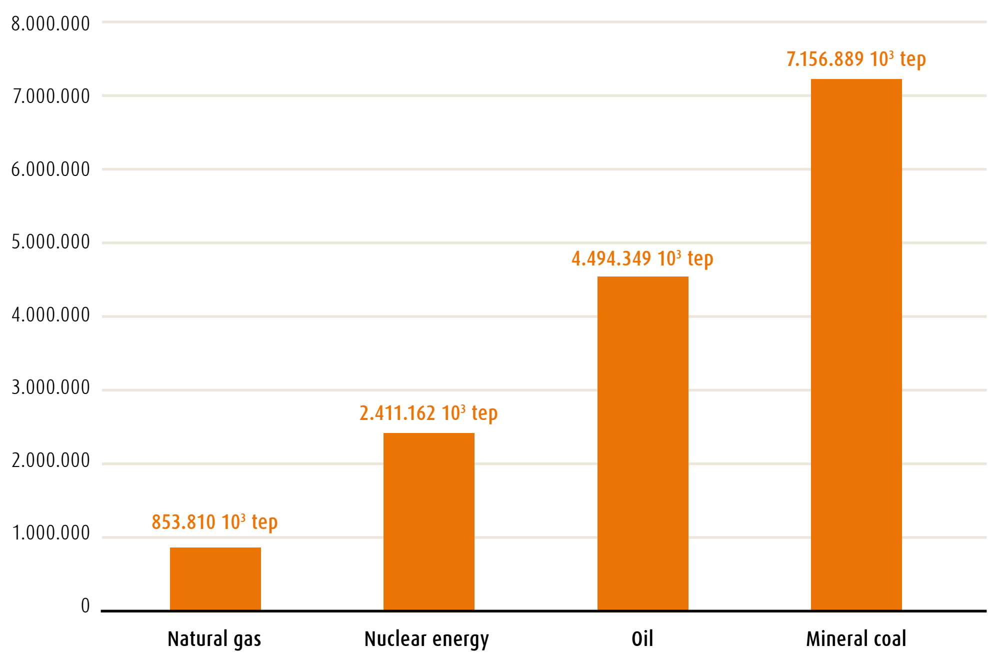


Source: Own elaboration, from EPE (2015).

serves of 309,000 tons of uranium, equivalent to 2.9 billion boe.

Eletronuclear operates two nuclear power plants, Angra I and II, and is currently building Angra III, which will double our capacity to generate electricity from uranium. The Northeast region holds the largest known reserves of uranium in Brazil, and it is there that Eletronuclear identified the best places to implement future projects of electricity generation from uranium. This aspect is relevant for PNE 2050, since the expansion of the nuclear power generation in the Northeast area would be an important regional development factor, in addition to wind and solar farms. For this new plan, the EPE proposes the construction of nine additional nuclear power plants, each one with 1,000MW. According to Eletronuclear, these plants should be built in the Northeast region.

Figure 10 | Brazil's main non-renewable energy reserves (in thousands of tonnes of oil equivalent)



NOTE: CALCULATED ON TOTAL RESERVES. IN RELATION TO THE MINERAL COAL IT WAS CONSIDERED A RECOVERY OF 70% AND A CALORIFIC VALUE OF 3,900 KCAL/KG. IN RELATION TO URANIUM LOSSES OF MINING AND BENEFICIATION ARE CONSIDERED. NO CONSIDERATION WAS GIVEN TO RECYCLING IN PLUTONIUM OR RESIDUAL URANIUM.

Source: Ministry of Mines and Energy, EPE.

When the nuclear energy is included in the Brazilian energy matrix, we must consider other aspects: costs, risks, waste disposal and regulation. The energy produced by these plants has low costs when compared to other sources. One kilogram of uranium produces the equivalent of 20,000 kg of mineral coal. The risks and destination of tailings are being solved with new technologies that already available. Currently, about 30% of the processed uranium in the world is already recycled.

The issue of regulation has been under discussion in the National Congress since 2006, when the report of the Nuclear Safety and Security Working Group was presented, recommending the creation of a committee within the Presidency of the Republic, which would be responsible for the normative, licensing and supervisory roles of the National Commission of Nuclear Energy (CNEN).

NON-RENEWABLE MATRIX

MINERAL COAL

Despite the technological advances achieved so far, the world remains very dependent on the use of fossil fuels to generate electricity and carry out some industrial activities. More than 40% of the energy generated comes from mineral coal, one of the most polluting sources. According to OECD/IEA publication (2014), there will be a world growing demand for coal at rates of 0.5% a year – which might be considered small, but should be decreasing. This scenario has already been worse, with growth of 2.5% a year in the last thirty years. For economic reasons, many countries insist on intensively exploiting this energy resource that causes serious environmental problems. The electricity sector accounts for 74% of global greenhouse gas emissions, mainly due to the intensive use of mineral coal.

Brazilian coal reserves are equivalent to the sum of oil, natural gas and uranium reserves. This grandiosity suggests that Brazil should take a strategic and careful look at the situation. Environmental costs and risks impose strict control over the uses of this source, using it in sectors where it cannot be replaced. Even in the face of these constraints, Brazil has a generating complex of 3.5GW (Aneel, 2015), located predominantly in the South region, where the main deposits are located. We consume approximately 10 million tons of coal annually. Given the availability of other sources, both clean and renewable, this generation complex could have been avoided. It was built mainly due to regional political demandswith an eye on implanting a production chain based on coal, and not at the choice of the electric sector. We must wait for new, cleaner and more competitive technologies, such as gasification, as well as the consolidation of the carbochemical poles, so that coal mining is carried out in a less aggressive way to the environment. (Figure 10).

Even with environmental restrictions, production costs and low quality of national coal, among others, the EPE still includes the expectation of construction of about 46 plants, each with 500MW within PNE's horizon. However, when drafting the decennial plans, the construction of these plants will certainly be postponed until the abovementioned restrictive conditions are adequately mitigated.

With a wide diversity of energy sources, Brazil should not include in its official energy matrix the possibility of using coal, except where its disruption may cause large social impacts. Therefore, PNE 2050 should recommend targets for the elimination of the use of coal, especially in the oldest electricity generation plants, since natural gas and wind energy (with good areas in the South region) can replace coal competitively.

Conclusion

As we have seen, Brazil is privileged regarding the internal availability of energy resources. Were it not for technological constraints, the country could meet all its needs with renewable sources. However, history has shown that world economic development was made without any regard for natural resources. When the combustion engine was invented with readily available oil, the entire world adopted this path without considering that pollution could cause serious environmental problems in the future.

When scientific research began to demonstrate that humans were overloading nature's ability to recover and the planet's temperature was reaching critical levels, society became aware that something had to be done to contain abusive and uncontrolled uses of natural resources. Several initiatives were adopted. And thanks to such efforts, we can still amend the mistakes of the past. The best examples are the increasing use of wind, solar and biomass energy. Major changes are already underway to replace vehicles powered by fossil fuels by electric vehicles with energy from alternative and renewable sources.

So far human beings have sought alternatives to produce economic development without considering the energy resource to be used. From now on, development strategies should consider the world energy matrix that must drive the future development.

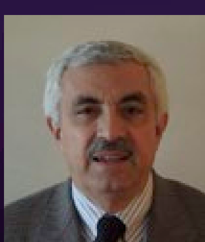
Environmental costs and risks impose strict control over the uses of coal, reserving it for activities in which it has no replacement.

In Brazil, as we have seen, development strategies should guide society in the use of renewable sources. In the Northeast, a region with great poverty and extensive semi-desert areas, the semiarid region could become a great generator of energy. There we may find the best winds and the highest levels of insolation in the country; 3,000km of coastline for the construction of offshore wind and solar power plants; the largest uranium reserves; 40 million people producing waste biomass and areas suitable for energy forests.

In the 1960s, it was decided that the development of the Brazilian Northeast would be done by industrialization. Today, the government could very well drive policies so that the Northeast could become the main supplier of renewable energy sources for the country. ■

Governance responses to the FOURTH INDUSTRIAL REVOLUTION

Industries, business models, professions and institutions will be increasingly affected by a new, ongoing wave of technological upheaval. The labour market and the performance of governments will be strongly impacted by the convergence of digital, biological and physical innovations. Traditional professions may disappear, giving way to new activities. Despite positive aspects, this process poses risks to the cohesion of societies, which requires a proactive stance of all the agents involved.



Guido Bertucci
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Background

Are we in the mist of a Fourth Industrial Revolution? According to Prof. Klaus Schwab, the Chairman of the World Economic Forum, who has written most extensively on the subject: "We are witnessing profound shifts across all industries, marked by the emergence of new business models, the disruption of incumbents and the reshaping of production,consumption, transportation and delivery systems. On the societal front, a paradigm shift is underway in how we work and communicate, as well as we express, inform and entertain ourselves. Equally, governments and institutions are being reshaped as are systems of education, health care and transportation, among many others."

It is difficult to argue that these changes and trends are not taking place. Whether we are placing them under the label of a "Fourth Industrial Revolution" or describing them as a natural progression of the "Third Industrial Revolution" is irrelevant. For sake of brevity and consistency, I will refer to them in this article as "The 4IR".

What is important is to identify the effects that they have on society, on business and on governance and take the necessary policy decisions to ensure that we reap their positive effects and minimize the negative ones.

The diagram below produced by the World Economic Forum, attempts to describe the extent of the changes ushered in by the 4IR.

The unprecedented changes ushered in by the 4IR consist of the fact that we are not only witnessing technological changes, but also systemic chances and an intersection and interdependence of different technologies (Schwab 2016).

Driven by the convergence of digital, biological and physical innovations the 4IR is affecting business models, changing production and consumption patterns, modifying the way individuals interact with each other and with governments, and thus producing a profound societal transformation (Schwab 2016).

We are witnessing how technologies such as quantum computing, the internet of things, 3D printing, big data, blockchain, machine learning, and on-demand economy are progressing exponentially and disrupting existing industries, businesses, professions, and institutions (Klugman, 2018).

The 4IR is also disrupting existing political, social and economic models and create a “distributed power system”. Such system will require stake holders to interact in a more integrated and collaborative way (Schwab 2016).

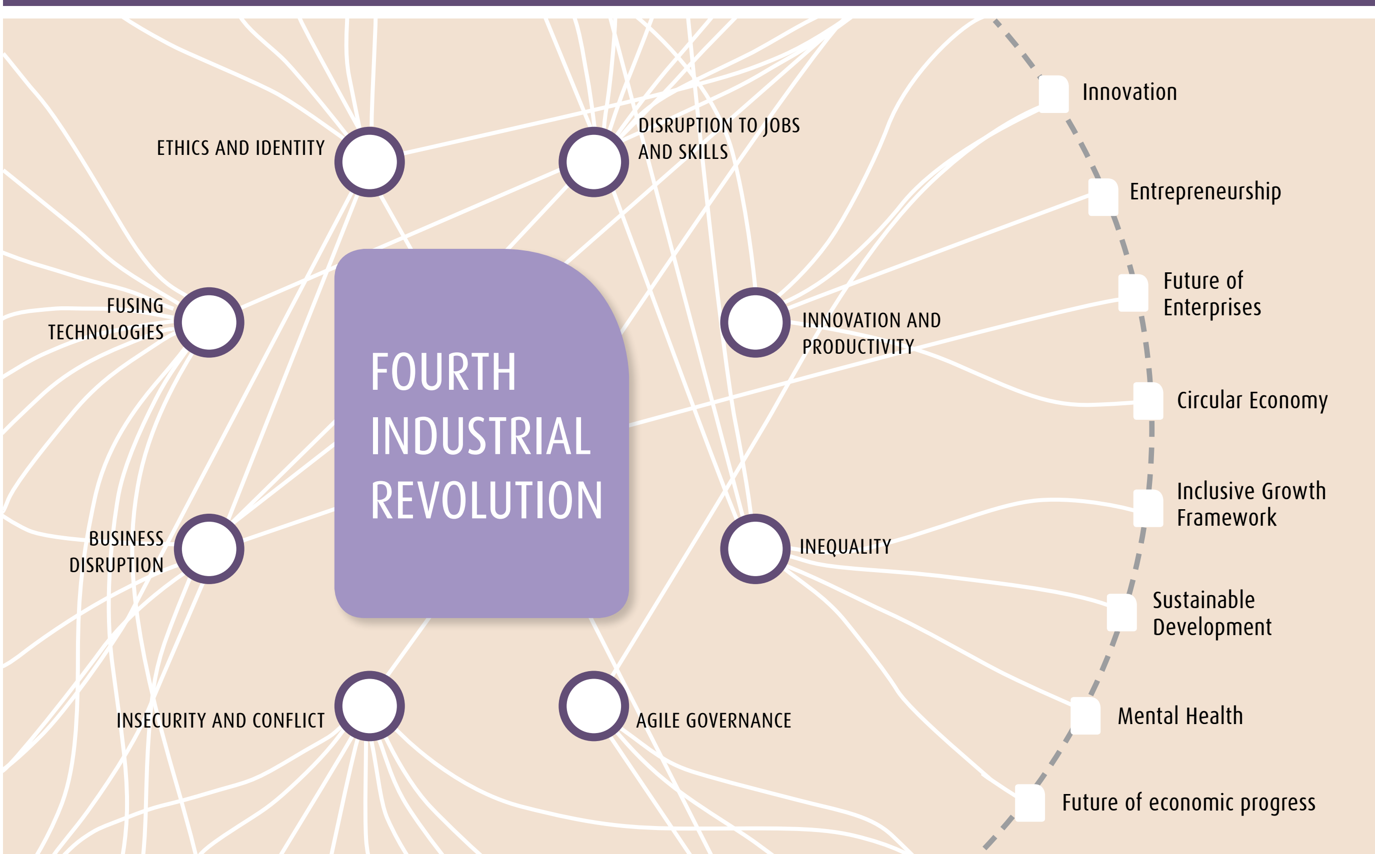
The modalities by which governments operate, their role and the way they interact with citizens will be seriously challenged by the advances of the 4IR.

Given the rapid pace of change, it is difficult to fully project what will be the positive consequences of the 4IR. Many analysts project that it will increase competitiveness, create an open, flexible and skilled-base economy (Lye 2017) and improve efficiency and effectiveness.

It has also the potential to increase income level and improve peoples’ lives

Consumers also have and will increasingly have access to new

Changes induced by the Forth Industrial Revolution



Source: W.E.F.

and cheaper products and services (Schwab 2016).

The new technologies are accelerating developments in education, improving access to information and giving citizens a voice. Sectors such as medicine, health, transportation, energy production and environmental protection will be positively affected by the new technologies.

On the other side of the coin, analysts have identified very serious negative consequences which can be produced by the 4IR.

It is expected that the job market will suffer the most serious negative effects as traditional occupations will disappear and occupations requiring new skills will grow.

A study carried out recently by McKinsey and Company envisages that existing technologies could replace half the time workers spend on their job.

We have seen how this phenomenon is creating a class of des-enfranchised workers and already having an effect on the outcome of elections in a number of countries.

While the new technologies improve the access to information, they can also undermine our privacy as access to data is more easily available to business, governments and even to other individuals in general.

As access to technology is essential to reap the benefits of the 4IR, those with limited access to the internet and those possessing obsolete knowledge and skills will be unable to benefit from the advancements; and thus economic, social and power inequalities may grow, both within countries and among countries.

The danger of utilizing advanced technologies for evil purposes, such as advanced weapons production, cyber-crime, hate speech, dissemination of "fake news" etc. will also increase.

Given the speed and scope of these changes Prof. Schwab and most experts strongly advocate a proactive approach on the part of all the affected actors, namely, governments, business and civil society.

"We have to win this race between the growing power of the technology, and the growing wisdom with which we manage it. We don't want to learn from mistakes", Max Tegmark, *Life 3.0.*

In the following chapters I will analyze more in depth how business, civil society and government are being and affected by the 4IR, with particular emphasis on governance. I will also touch upon briefly on the consequences for global governance systems.

Businesses

The technological advancements are exponentially disrupting existing industries and increase competition by providing digital platforms for product development, marketing and distribution (Schwab 2016). New services are constantly developed and offered to the consumers.

Prof. Schwab summarized the four main effects of the 4IR on business, namely on customer expectations, on product enhancement, on collaborative innovation and on organizational forms.

To stay relevant and profitable, companies need to constantly reinvent themselves to become more flexible and open to innovation.

As the supply side of business is changing, we also witness the shifts in the demand side and the emergence of new platforms that combine both demand and supply, particularly through smartphone technology (Rao, Srinagesh and Sreedhar 2017).

The emergence of a new, innovative and agile competition forces business to become more flexible and to constantly re-invent itself to remain relevant and profitable.

Within this scenario, the linkages between science and business need to be strengthened as commercial utilization of artificial intelligence and robotics is growing.

The most disrupting effect of the 4IR on business, and, as I mentioned before, on the society as a whole, is the transformation of the labor market, as new skills will required and other will become obsolete. According to Marc R. Benioff, Chairman and Executive Officer of Salesforce, In the

Confidence in institutions may diminish, opening spaces for an anti-government populism in some countries. Citizens will interact more with governments, demanding faster and better.

US alone there are more than 500,000 open technology jobs but only 50,000 science students are graduating from universities each year. Millions of jobs need to be filled in computer science, mathematics and engineering. At the same time, administrative and white collar positions will dramatically decrease according to the World Economic Forum. And certain geographic areas where jobs will disappear will suffer economic and social downturn and disruption.

Businesses, therefore, need to proactively prepare a new workforce as highlighted in a joint report from Deloitte and the Global Business Coalition for Education entitled "Preparing Tomorrow's Workforce for the Fourth Industrial Revolution." According to the report," business should take a more proactive role in preparing today's youth to insure their readiness to be the workforce of tomorrow." The report recommends that business, among other things,"should engage strategically in public policy, develop promising talent strategies and invest in workforce training."

Business leaders should be encouraged to team up with educational institutions, also by providing financial assistance in developing education and training programs required for the workforce of the future.

Civil Society

As mentioned before, the transformation in the labor market brought forth by the 4IR will have negative effects on social cohesion, generate a decline in public confidence and, in some countries, give rise to anti-government populism (Klugman 2018). It will be therefore the responsibility of governments, in cooperation with the private sector, to rebuild trust and confidence through appropriate policies aimed at mitigating such disrupting effects.

Citizens, who are accustomed to reap the benefits of the new technologies in receiving services from business, will increasingly demand better and faster services from governments.

On the positive side, the new technologies provide to citizens better opportunities to interact with government, to express their views and to engage in policy development and implementation

Governments

The advent of the 4IR poses tremendous challenges for governments and for governance systems and institutions. How governments will respond will determine whether countries and societies will be able to reap its benefits and minimize its negative effects.

In the following chapters I will endeavor to outline possible courses of action by governments in general and in a number of specific areas such as: Public Policy Development, Governance Systems, Legislation and Regulation, Cyber Security, Taxation, Human Resources Development, Public Service Delivery and Citizens' Engagement, Big Data and Implications for global governance.

Public Policy Development

The pace of technological, digital and social change is so fast that governments find it difficult to take policy decisions and enact regulation to keep pace with the changes. The current systems of decision making, grown in the context of the Second Industrial Revolution, involve lengthy processes and steps (Schwab 2016).

The pace and complexity of the 4IR requires that governments adopt a systemic approach to problems rather than a piecemeal one, as suggested by the OEDC and the World Government Summit in their 2018 report "Embracing Innovation in Government".

According to the report, *systems approaches* "are a set of processes, methods and practices that aim to affect systems change….

Systemic tactics for the challenges of the public sector

Source: OECD

going beyond the linear logic of input-output". In short government need to develop a comprehensive response to the interconnected problems brought forward by the 4IR.

Governments also need to strengthen their capacity to diagnose problems, to forecast and to build alternative scenarios. According to David Lye, Director of Sami Consulting, governments need to become "future-savvy".

A number of governmental agencies in a few countries have established forecasting units which have developed sophisticated software-based diagnostic and forecasting tools. The utilization of A.I. as a tool for decision making could also be explored. Regrettably, the political class in most countries proposes solutions based on ideology rather than such diagnostic tools.

A new era of agile governments would be required with the capacity to adapt continuously to the fast pace of change Schwab (2016). According to Kris Broekaert and Victoria A. Espinel agile governments involves policymaking which is adaptive, focused on achieving policy goals, open to new information and data, and open to input from a wider group of stakeholders.

Governments need to prepare rather than react and to create the mechanism to manage the transition. Traditionally innovation has come from outside government. (Jarrar 2016). It is essential that governments strengthen public agencies to enable innovation within government. Governments therefore should become engines of innovation rather than reactive actors.

In addition, governments should become facilitators for innovation in business and in society to thrive. A report entitled "Gov2020" prepared by Deloitte for the World Government Summit in 2015, identified a number of trends with the potential to reshape governments in the face of the 4IR. Governments are becoming enablers instead of providers of solution. They thus build platforms for partnerships among different actors. The report also highlights the fact that increasingly governments functions are being co-created with citizens. Through technology and crowd sourcing, systems of "distributed governance" are being developed. In addition, the report emphasizes what I mentioned before, namely that governments should be "data smart" and utilize modelling and data analysis for prevention rather than reaction.

Distributed government systems involve further decentralization of responsibilities from central to regional and local governments as well as the inclusion of multiple actors in the decision making process. As business, civil society and government are responsible for producing innovation, they should also collaborate in designing the necessary measures to develop and design the most appropriate responses to the effect of the 4IR (Yun 2018). Distributed governance will also go a long way to regain the trust in government that has suffered in recent times.

The power of technology will perforce make government more transparent and accountable as information on government operations will be more available and accessible and widely disseminated. To the extreme, we will see the growth of phenomena such as Wikileaks.

In terms of content, Access Partnership suggests a roadmap which identifies three key areas for governments to address, particularly to promote the hypercloud:namely, promoting infrastructure; creating the right incentive for adoption and further innovation; and upscaling of the workforce.

In its report entitled "Delivering the Fourth Industrial Revolution: The Role of Government." The report further elaborates on the three key areas mentioned above. Concerning the promotion of infrastructure to participate in the 4IR, it recommends that governments should invest resources strategically to support internet infrastructures; foster interoperable internet and make high speed internet affordable. With respect to creating incentives for adoption and promoting innovation, governments should encourage participation in the global hypercloud market; support global cloud computing standards, support data driven economy and service provision; implement modern privacy laws and create light-touch legal frameworks. Finally, with respect to the task of promoting a workforce for twenty first century jobs, government should aspire to build a flexible workforce with critical thinking and problem solving abilities; integrate digital skills in basic education; support computer science education and retrain workers for lifelong learning.

In order to implement such policies, major steps will need to be taken to bridge the divide in connectivity. This is an area where many governments lag far behind.

In order to promote innovation and accelerate technological

> We will need to adapt governance systems to a new reality, making them more flexible and less fragmented, with stronger coordination mechanisms. Legislation will need to be modernized.

advances, governments should improve the fluidity of capital and promote the growth and development of SMEs.

Governance Systems

As previously mentioned, the advent of the 4IR will require changing the current policy making processes to make them faster, more agile and responsive. Also the utilization of information and data, particularly Big Data, should support the decision making process. Finally, the participation of government, business, civil society, and as appropriate, international organizations in developing policy solutions should be strengthened. But in addition to changing policy making processes it will be essential to adapt governance systems and processes to the new reality.

Current systems are at the same time rigid and fragmented, with agencies often operating in silos, making thus difficult to develop and implement comprehensive policies.

In order to properly address the challenges of the 4IR stronger coordination mechanisms should be established to allow for comprehensive responses.

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> **The new industrial revolution will also cause changes in educational policies. We will have to train people who are better adapted to the new labour market and who have a strong leadership skills.**

Another option would be the creation of new institutions entrusted with the responsibility to govern technology. These institutions would need to be multi-stakeholder based in order to incorporate the inputs of business and civil society.

The creation of a dedicated governmental organization responsible for the formulation of strategic plans and manage change has been the option followed by few governments. For example, the government of the United Arab Emirates has created the "Ministry of the Future and Change Management", a non-partisan independent body, responsible for agenda setting, such as developing future strategic plans; for supporting policy development and regulation; for change management and implementation; and for monitoring the progress. In 2017 the Ministry published a report entitled "The UAE's Fourth Industrial Revolution Strategy" which was designed to provide a practical framework for policy makers and support national efforts in adopting advanced technologies and transforming future challenges into opportunities.

As already mentioned, governance systems would need to be more decentralized, with additional responsibilities entrusted to regions and cities. At same time appropriate measures should be taken to support them to enable them to serve more and more as hubs of innovation. (Schwab 2016).

Legislation and Regulation

Given the fast pace of progression of the 4IR, legislation and regulation are hardly capable of keeping up with the pace.

However, it is essential that technological advances be quickly regulated in order to enable them to produce their positive effects and to minimize the negative ones. Regulators consequently have less time to evaluate the impact of the developments and to take appropriate decisions. New mechanisms and processes to enact legislation and to issue regulation must be developed. Coordination among regulatory bodies should also be strengthened as the 4IR is affecting concurrently many technological and social fields.

While protecting society and consumers, the regulatory framework should be creating the enabling environment for innovation to thrive. (Schwab 2016).

Governments have traditionally been the principal developers of regulation; however, we have witnessed the emergency of "new sources of authority" to govern the new technologies. Businesses and industry can come up with innovative solutions on regulation, and can establish norms for self-regulation. With the emergence of self-regulating bodies, governments could act as super-regulators authorizing and evaluating the work of such bodies (Broekaert and Espinel 2018).

In lieu of regulations, the utilization of best practices can address rapid and broad developments more swiftly. For example, the US National Institute for Standards and Technology (NIST) established with the input from the private sector, government agencies and privacy and security communities, best practices for cyber security rather than establish new standards.

With respect to the contents, new intellectual property regimes should be regulated as well as cyber security protocols and ethical standards adopted.

Cyber Security

As technology becomes widely accessible, the possibility of its utilization for nefarious purposes increases in parallel. To protect themselves from cyber-crime ranging for hacking of data bases, including election data bases; cyber attacks to energy, health and transportation facilities; cyber terrorism; etc., governments will incur very high costs (Shava and Hofisi 2018).

The International Telecommunication Union (ITU), recommends a 5 prong approach to strengthen cyber-security, covering legislation and regulation, technical measures, organizational arrangements, capacity building and inter-state cooperation.

Together with the I.T.U., a number of experts recommend the establishment of an agency responsible for coordinating efforts in this area.

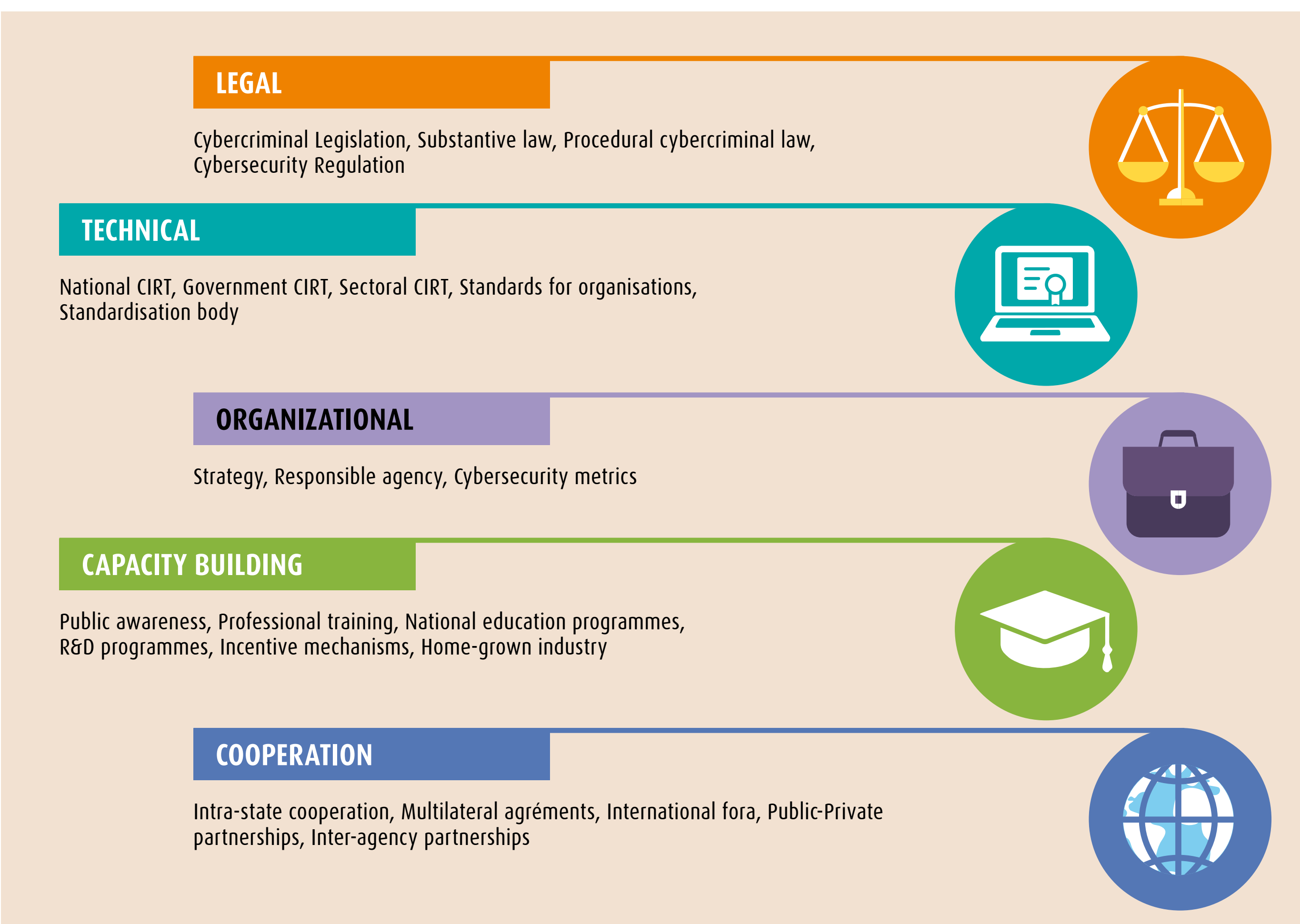
The United Nations e-Government Survey 2018 recommends that countries establisha computer emergency response team (CERT) or a computer security incident response team (CSIRT) that responds to computer or cybersecurity incidents. It also highlights that, apart from Europe and Asia, countries are lagging behind in this endeavor.

Taxation

The shifts in economic patterns are creating serious challenges for the collection of taxes. Digital and decentralized payment systems limit the ability of tax authorities to keep track of transactions (Schwab 2016).

Novel modalities to tax new types of business and financial transactions should be developed. For example, Estonia is the first country to collect transaction taxes via a blockchain.

The five parts of cyber-security



Source: I.T.U.

JinHyo Joseph Yun recommends that also the national taxation structure be overhauled to redistribute income and capital concentrating in large companies. He also recommends that instead of taxing labor, which will be negatively affected by the 4IR, productivity should taxed.

In the same vein, Bill Gates proposed that robots be taxed as they will be replacing human beings in the production chain.

Human Resources

It has been mentioned earlier that it is estimated that the 4IR will have a negative effect on the labor market. As the need to develop a new workforce increases, government will need to invest heavily in reforming education policies to ensure that those policies generate knowledge and skills required by the new labor market. Business together with government should utilize forecasts already available to determine the jobs which would be more likely subject to automation and those jobs which will increasingly available. In light of such forecasts, education and training policies should be developed to respond to the forecast changes.

In addition to a new workforce, new leaders will be required in order to manage people not sitting in their offices, but who will connect virtually (Art-

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ley 2018) As professor Schwab writes, "We need leaders who are emotionally intelligent, and able to model and champion co-operative working."

As lack of workforce skillshamper economic growth and are likely to create unemployment in the private sector, the government workforce will also be negatively affected. As has been mentioned earlier, it is estimated that white collar and administrative jobs will be those more likely to become obsolete. With the further development of e-government to carry out governmental transactions, governmental organizations will require fewer administrative staff. Instead they will require personnel with computer training. Governments, therefore, should urgently embark on massive retraining programs for their employees.

In its previously mentioned report "Gov2020" Deloitte estimates that government will shift its hiring practices by applying the consulting staffing model for its workforce. It would utilize employees who are part of joint ventures, employees of contractors, independent individual contractors and people who don't work for government at all but who are part of a valued chain of services.

There is a set of skill; however, which would be much in demand which cannot be performed by machines. These are creativity and innovation, leadership, emotional intelligence, adaptability and problem solving. According to a survey carried out by OECD, a large percentage of organizations indicated that it was somewhat difficult or very difficult to recruit people with such skills.

Governments and businesses will deal with increasing amounts of data from more sources. Volume, variety, speed and truthfulness are the four concepts that guide jobs.

Public Services Delivery and Citizens' Engagement

The advances of the 4IR, could accelerate and improve service delivery to citizens by governments. Governments could also introduce methods utilized by private sector companies to deliver public services more efficiently, faster and more flexibly (Klugman 2018).

The United Nations 2018 e-Government Survey "highlights a persistent positive global trend towards higher levels of e-government development.... Countries are advancing towards higher levels of e-government... The number of countries providing online services using emails, SMS/RSS feed updates, mobile Apps and downloadable forms has been increasing in all sectors...Provision of services through mobile Apps is growing fastest in the education, employment, environment sectors".

The report also notes how innovative public-private partnerships (PPPs) have emerged as models for the provision of public services and social entitlements in areas such as education, health and environmental sustainability.

As advances in digital technology accelerate and as communications and information migrate to digital platforms, "citizens are changing their approach to interacting with governmental organizations and services. A more horizontal, spontaneous and empowering relation is developing, as opposed to the traditional hierarchical relation" (Jarrar 2017).

There is the opportunity to engage and empower citizens by providing digital platforms to seek their views; to involve them in decision making; to design and deliverservices; and to increase control and accountability of public organizations.

The United Nations measures citizens' engagement in public affairs through an E-Participation Index (EPI); in its 2018 report it notes that the number of countries with a very high EPI has doubled from 31 to 62 since 2016, demonstrating how fast the new technologies can change the relations between governments and citizens.

Big data

It has been mentioned above how crucial is the availability of data for decision making purposes.

The the volume of data growing exponentially has given rise to the concept of "big data", namely those defined by the four "Vs": volume, variety of sources, velocity and veracity.(Jarrar 2017) The primary challenge is to be able to utilize and manage the big data on the part of both business and government.

Data have become a source of wealth, described by some as "the new oil", or the "lifeline of the digital society".(Jarrar 2017)

The majority of data is now owned by the private sector, but governments also produce and store a considerable amount of data. As data can actually be monetized, the question arises on who should own the data.

New legislation is required to regulate how data are stored, managed, shared and protected. Some experts recommend the establishment of a "data charter". Data can be considered a "social good" and as such government has a responsibility that they be utilized to produce public value.Government thus may need to acquire a new capability, that of "data curator" (Jarrar 2017).

As data are essential for the creation of public value, governments are increasingly making available data to civil society, businesses and individuals. The so called "Open Government Data (ODG)" help to improve service delivery in areas such as health, education, environment, welfare etc.According to the United Nations, the number of countries with Open Data portals has reach 139.

With a view to promote the harnessing of big data safely and responsibly as a public good, the United Nations has launched an initiative called "Global Pulse", which has the objective to acceleratethe discovery, the development and the scaled adoption of big data innovation for sustainable development and humanitarian action.

Implications for Global Governance

The advent of the 4IR is having an impact well beyond national boundaries, requiring the forging of new agreements and possibly the creation of new global governance mechanisms. According to Prof. Schwab, we "need a comprehensive and globally shared view of how technology affects lives". A report prepared for the 2017 G20 meeting in Germany highlights the lack of a "global regime for technological governance".

The same report includes a number of recommendations addressed to the G20 members, namely that the G20 should champion international technological governance structures; should identify and promote essential safeguards to ensure a sustainable 4IR to minimize unintended negative consequences; should promote a coordinated effort by governments and regulators to identify and manage systemic risks emanating from the 4IR; and should encourage countries to develop responsible technology policies, which would include employing social and environmental considerations in countries' national digital strategies.

Finally, one should bear in mind that the advancement of the new technologies will also have an impact on international security and affect the nature of conflict. (Schwab 2016). Therefore, the need will arise to establish a new international conflict resolution mechanism. (Segal 2017).

The World Economic Forum is the international organization that has been most active in highlighting the rapid transformations ushered in by the 4IR and their impact. With a view to fostering "multi-stakeholder dialogue and concrete cooperation on challenges and opportunities presented by advanced technologies", it has opened a Centre for the Fourth Industrial Revolution, located in San Francisco. The mission of the Centre, which brings together governments, civil society, business, academia and international organizations, is to "facilitate the co-design, testing and refinement of governance protocols and policy frameworks to maximize the social benefits and minimize the risks of advanced science and technology".

Conclusions

Will the 4IR help us to improve our living standards, our well being and our environment? The potential is enormous but so are the risks. The technological changes are so rapid that businesses and governments are constantly playing a "catch up" game. In order not to be overtaken by the advances, a proactive and anticipatory approach is required. Governments, in cooperation with business and civil society, need to develop long term and comprehensive strategies which include policy, regulatory and structural measures. New national governance paradigms will need to be designed to allow rapid, agile and participatory decision making. As the scientific and technological developments have effects beyond national borders, also global governance arrangements will need to be overhauled to facilitate global responses, particularly in the areas of cyber-crime and cyber-terrorism. Could the G20 be the forum to spearhead global action to address the challenges? ■

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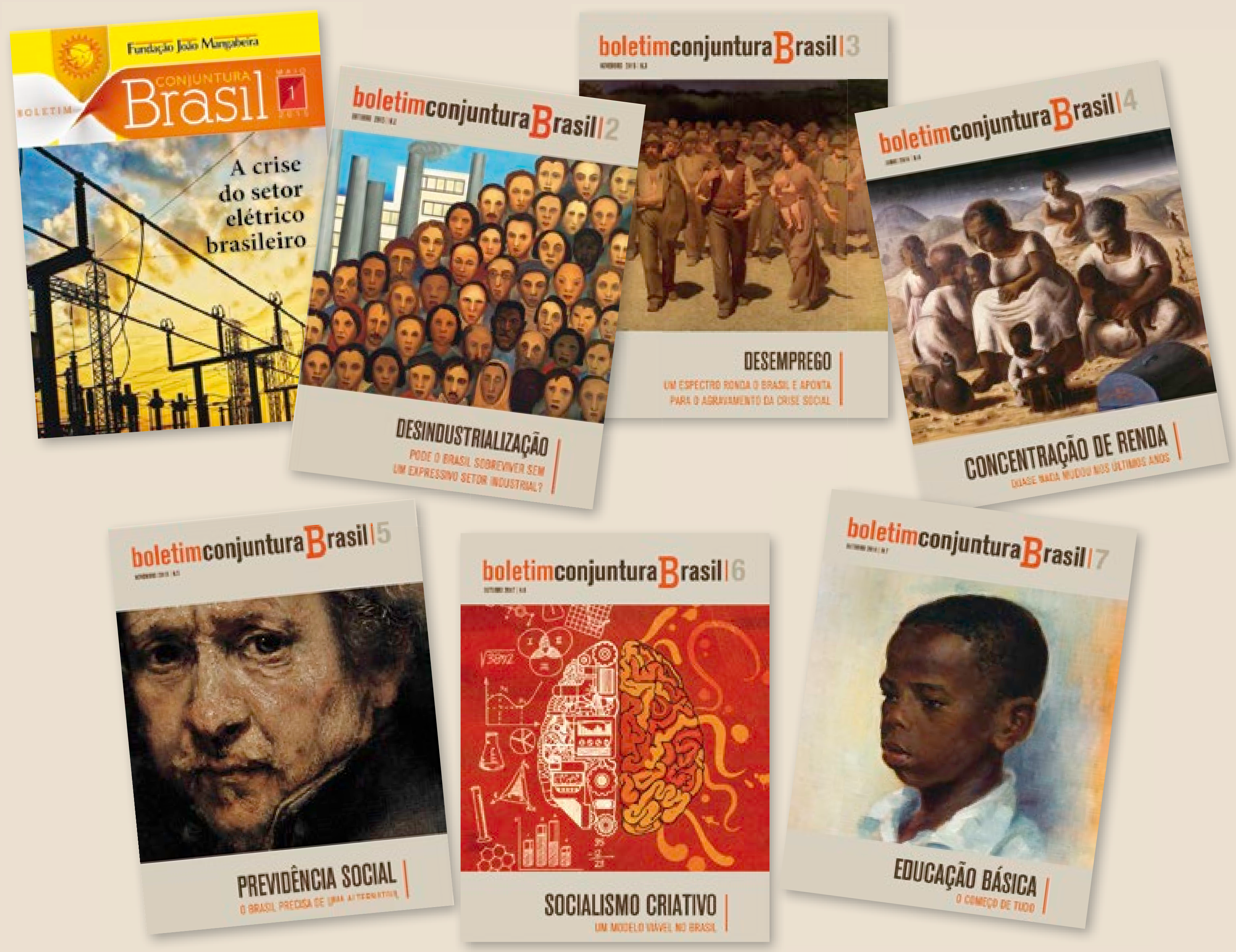

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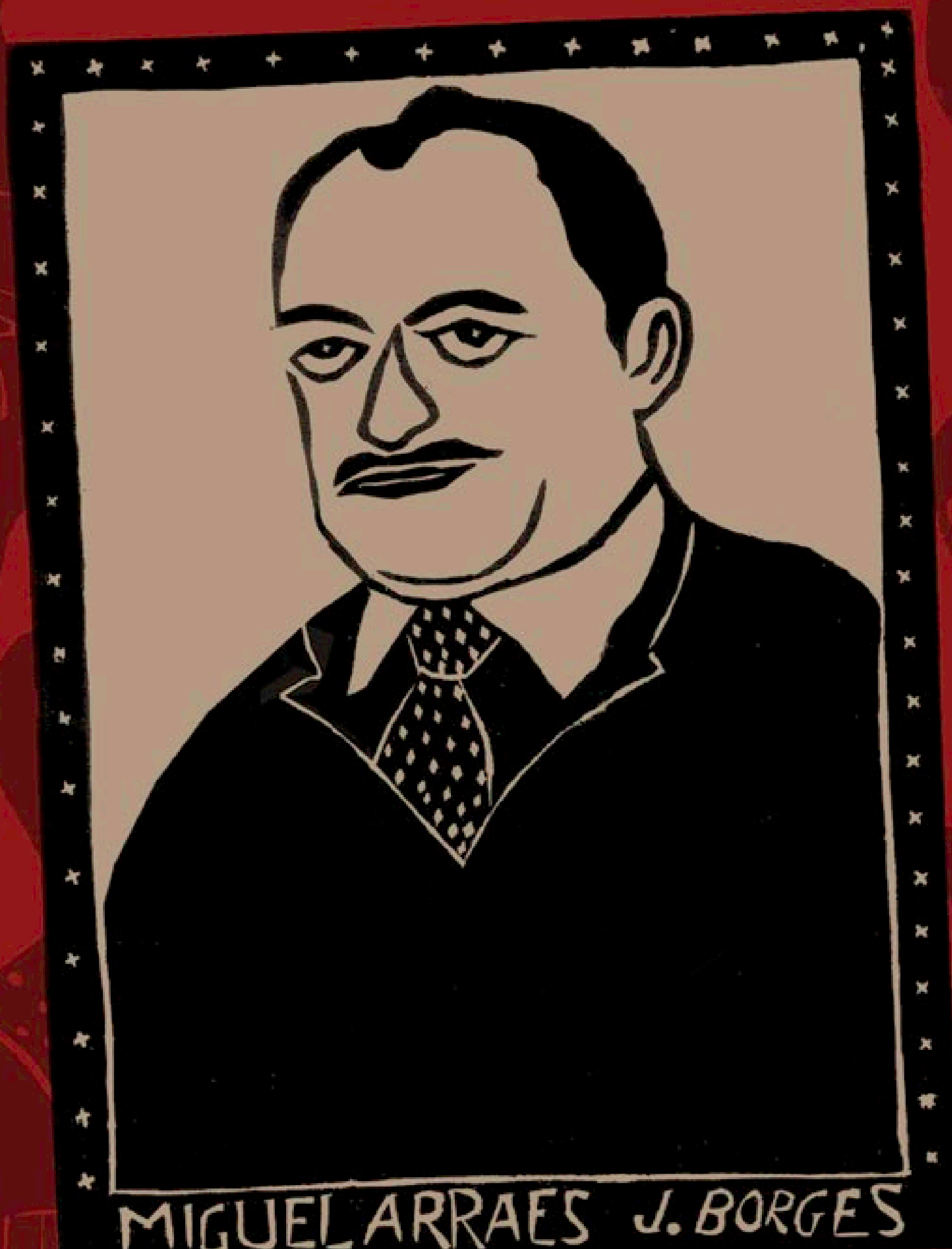
MIGUEL ARRAES
NATIONAL HERO



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