INTRODUCTION

This paper addresses the different trajectories adopted by Brazil, China, Taiwan and South Korea regarding the development of low carbon energy technologies. Comparing the policies and legislations enacted by these countries in the last two decades, we analyze how late industrialized countries, with different availability of energy resources within their territories, are coping with the obstacle posed by climate change to its development targets.

The situation that these four countries face regarding climate change is dramatically different. Whereas Brazil has a relatively clean energy mix, the other three rely heavily on carbon intensive energy sources. The situation presses the Asian countries to find low carbon technologies as a strategic need for its long term growth due to the emerging international climate change regime. In the case of Brazil, it enjoys a relatively comfortable situation due to its possibilities of reducing emissions in areas other than the energy sector, such as land use change and agriculture.

On the other hand, Brazil has not structured a robust national innovation system, which turns further development of its clean energy mix more difficult. The Asian countries were able to build a national system of active learning, gradually moving to a national innovation system. That allows them to leapfrog towards the state-of-the-art of the low carbon technologies.

In this context, we argue that, even though Brazil has a cleaner energy mix and a lower carbon emission rate than China, Taiwan and Korea, its industrial sector is not leading the competition for innovation in low carbon technologies. Inversely, the Asian countries are investing heavily in low carbon energy innovation. Even they are taking part in the global contest for these technologies, the three Asian countries are doing so without abandoning the intense use of polluting sources of energy.

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THE DIFFERENT NEEDS TO REDUCE EMISSIONS AMONG COUNTRIES

An international climate change regime is gradually being forged over the last two decades. Beginning with the United Nations Framework Convention on Climate Change, in 1992, and going through its annual Conference of the Parties, people’s comprehension about the necessity to establish limits on greenhouse gas emissions became increasingly robust. Even though the efforts to approve a mandatory international climate change regime in the Copenhagen Conference failed, a bottom-up approach is gaining momentum, with moves from different nations and social sectors taking place (MACHADO, 2012; e FRIEDMAN, 2009).

This scenario is forcing all the countries to revisit its own development strategy in order to maintain the long term growth of the economy and to prevent it from turning excessively dependent on energy imports (VIOLA, FRANCHINI & RIBEIRO, 2013). With that in mind, it is important to take note of the situation of the four late industrialized countries examined in this paper to find out the different needs each one deals with in climate change negotiations. Table 1 summarizes the most important data on these countries, adding information on US and Europe to put the data into a broader context.

### TABLE 1
Indicators on some of the most important players in climate change negotiations

<table>
<thead>
<tr>
<th>Country</th>
<th>Population 2011, in millions (% of world total)</th>
<th>GDP 2011, in billions of US$ (% world total)</th>
<th>CO₂ Emissions in 2011, in billions of tons</th>
<th>CO₂ Emissions in 2011, in tons per capita</th>
<th>CO₂ Emissions per GDP in 2011, in billions of tons per US$ 100.00 of GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1,345 (19.2)</td>
<td>7.3 (10.5)</td>
<td>9.70</td>
<td>7.2</td>
<td>1,329</td>
</tr>
<tr>
<td>European Union</td>
<td>501 (7.1)</td>
<td>17.6 (25.3)</td>
<td>3.79</td>
<td>7.5</td>
<td>215</td>
</tr>
<tr>
<td>USA</td>
<td>315 (4.5)</td>
<td>15.1 (21.7)</td>
<td>5.42</td>
<td>17.3</td>
<td>359</td>
</tr>
<tr>
<td>Brazil</td>
<td>194 (2.8)</td>
<td>2.5 (3.6)</td>
<td>0.45</td>
<td>2.3</td>
<td>180</td>
</tr>
<tr>
<td>Korea</td>
<td>48 (0.7)</td>
<td>1.1 (1.6)</td>
<td>0.61</td>
<td>12.4</td>
<td>555</td>
</tr>
<tr>
<td>Taiwan</td>
<td>23 (0.3)</td>
<td>0.5 (0.7)</td>
<td>0.27</td>
<td>11.8</td>
<td>540</td>
</tr>
</tbody>
</table>


Brazil has very low levels of per capita emissions (less than 3) and its economy is not so much energy intensive (less than 200). The figures for Brazil contrast sharply with the situation of the three Asian countries: Korea and Taiwan show high levels of per capita emissions (above 10 per capita) and also significant levels of emissions per unit of GDP (above
500). China displays a moderate-to-high level of carbon per capita (between 5 and 10) and, in terms of carbon intensity in the GDP, and it has spectacularly high rates (more than 1,000).

With an expected tendency to the foundation of a global climate change regime, which would limit the amount of carbon each nation can emit, the four countries face very different challenges. In the case of Brazil, most of its emissions used to come from deforestation – not from the energy sector. Thus, one can understand the successful efforts in Brazil during the last decade to decrease in about 80% the level of illegal deforestation in the Amazon. Data show, therefore, that Brazil does not need to be on a hurry to attenuate its greenhouse emissions from the energy sector. Graph 1 reveals that in five years Brazil reduced its total emissions in about half mainly by the reduction of logging activities.

**GRAPH 1**

Emissions of 2.03 billion tons of CO₂-eq in 2005

Emissions of 1.25 billion tons of CO₂-eq in 2010

Source: Ministry of Science, Technology and Innovation in Brazil, 2013

China, Taiwan and Korea, on the other hand, have no other option to reduce its carbon emissions, but to change its energy mix. Since energy is a very powerful and pervasive sector of any economy, the challenge to transform the sources used by a country implies costly investments. Therefore, it makes sense for these nations to invest in new technologies and, simultaneously, keep using traditional and cheap sources of energy to gradually depreciate past investments and to provide a smooth transition to a low carbon energy mix.
The availability of energy sources is another factor that affects the calculations of decision makers in the four countries surveyed. Brazil and China have both large sources of energy within their territories, but the Chinese ones are mainly carbon intensive, especially coal. Brazilian ones are concentrated on renewable items, such as biomass and hydropower, but they also comprise huge offshore fields of oil and gas.

In other words, oil and gas aside, Brazil has room to grow using traditional sources of energy without harming so much the environment – and oil and gas is not seen as a terrible option for a country with comparatively low levels of emissions (BRASIL, 2013).

If China decides to use most of its coal, the damage to global – and local – environment would be substantial. All in all, coal is the source of energy that generates the highest amounts of greenhouse gases. Moreover, Chinese economy is the second biggest in the world: an extra move from such a huge player would provoke worldwide impacts.

Taiwan and Korea, differently, are very much dependent on imports – they bring from outside more than 97% of the energy needs (US ENERGY INFORMATION ADMINISTRATION, 2014). For both countries, finding new sources of energy, especially if available within their territory (such as solar or wind) would benefit themselves immensely by diminishing the daily need to import and by reducing their geopolitical vulnerability.

**GRAPH 2**

**Sources of energy**

Source: US/EIA
Again, Brazil is in a comfortable situation, without the hurry to find new sources of energy. It expects to keep growing without increasing significantly its emissions from electricity generation or transportation. The three Asian countries, differently, have an urgent need to discover new sources of energy. Novel technologies would benefit them by reducing local pollution (especially in China) and by decreasing the dependence on imports.

Graph 2 shows that clean sources represent a big amount of the energy mix in Brazil. Additionally, the country still has a lot of underused arable land that can be converted for biomass production (THE ECONOMIST, 2010). Finally, there is also plenty of unexplored hydropower – though much of it is on the Amazon Basin (BRASIL, 2013). All the Asian countries utilize mainly carbon intensive sources of energy, especially coal in China and oil in Korea and Taiwan. None of the countries have much wellspring of clean energy available in their territory (US ENERGY INFORMATION ADMINISTRATION, 2014).

NATIONAL LEARNING SYSTEMS

The relatively comfortable situation in Brazil regarding low carbon energy adds to the passive learning system that characterized its late industrialization. The so-called passiveness can be explained by five factors: most of the technical learning process was made via foreign direct investment; the workforce is on average lowly skilled; investments in R&D are meager; integration between companies and public research institutions are fragile; industrialization was not focused on exports, but primarily in import substitution (DUBEUX, 2010; VIOTTI, 2001).

Furthermore, the availability of huge amounts of natural resources – especially iron ore and agricultural goods – has produced a tendency for overvaluation of its currency. This chronicle “Dutch Disease” – instead of an acute one – has created additional hurdles for local industries to innovate and to compete with foreign companies in technology intensive areas (BRESSER-PEREIRA, GALA & ARAÚJO, 2010; OREIRO & FEIJÓ, 2010).

The situation is very different from the ones observed in China, Taiwan and Korea. Though each nation unfolds certain peculiarities, there are common traits that allow the classification of their national learning system as active ones. Instead of grounding the technology absorption in foreign direct investments, they did it mainly by imports of machinery (China received a lot of foreign investment, but mostly via joint ventures with local companies) (LONG, 2005; TSENG & ZEBREGS, 2002; McKINSEY, 2010). The workforce of these countries achieved high level of education in standardized tests (China does not show that for the country as a whole, but some of its provinces did it, especially Shanghai) (PISA, 2013). Investments in R&D grew sharply. Local companies work together in many areas with public institutions of research. Lastly, industrialization was particularly focused on exports, forcing
companies to survive in competitive markets, instead of prioritizing local, protected markets (KIM, 2005; LIU & LIU, 2004).

Additionally, the lack of natural resources did not create the problem of currency overvaluation for any of these nations. On the contrary, all three countries exhibited most of the time undervalued currencies, helping its industries to compete in foreign markets.

The result can be seen in Table 2, which summarizes the number of patents of clean energy technologies registered in the United States Patents and Trademark Office. As one can see, Brazil only shows 16 patents, whereas China displays 91, Taiwan goes on 389 and Korea achieves impressive 840. Graph 3 shows the increase, year to year, in the amount of patents in clean energy technologies for the four late industrialized countries.

**TABLE 2 AND GRAPH 3**

**Patents in USPTO**

By technology and by residency (2002-2013):

<table>
<thead>
<tr>
<th>Country</th>
<th>Fuel Cells</th>
<th>Solar</th>
<th>Wind</th>
<th>HEV</th>
<th>Bio-mass</th>
<th>Ocean</th>
<th>Geothermal</th>
<th>Hydro</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>China</td>
<td>15</td>
<td>35</td>
<td>20</td>
<td>16</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>91</td>
</tr>
<tr>
<td>Korea</td>
<td>574</td>
<td>139</td>
<td>22</td>
<td>108</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>840</td>
</tr>
<tr>
<td>Taiwan</td>
<td>127</td>
<td>185</td>
<td>47</td>
<td>14</td>
<td>2</td>
<td>11</td>
<td>0</td>
<td>3</td>
<td>8</td>
<td>389</td>
</tr>
</tbody>
</table>

By residency, year to year


The contrast among the paths adopted by each of these countries can be summarized in two Charts. Chart 1 reveals how Brazil developed from a passive learning system to a dependent industrial modernization in the energy sector. Though the country generates energy from low carbon sources, including hydro, wind and biomass, most of the technologies used are developed outside of the country. Climate change is not seen as a big and imminent threat to the country’s growth trajectory and there are abundant fountains of energy within its territory. The passive learning system forged during its industrialization is aided by an appreciated currency to keep innovation in local companies in low levels. Energy policies reflect
a relatively comfortable situation, without major efforts to change its mix or to force the creation of new domestic technology.

**CHART 1**

Dependent industrial modernization

- Climate change regime reasonably solved
- Energy security reasonably solved
- Passive learning system
- Overvalued currency
- Policy towards importing technologies and excessive bet on traditional sources of energy
- Dependent energy industry

China, Taiwan and Korea, on the other side, surpassed their active learning system and built a gradually autonomist industrial modernization in the energy sector. Feeling threatened by the climate regime and facing excessive dependence on imports, their decision makers felt the urgency to invest in new technologies. Local innovative companies, helped by depreciated currencies, were induced by government policies to create new technologies for low carbon energy generation and storage, a move condensed in Chart 2.

Graph 3 shows the result of these moves. In terms of clean energy generation, Brazil produces proportionally more than the others, exhibiting about half of its energy mix with low carbon technologies. It does manufacture a big part of the machinery needed to energy generation, but most of it comes from foreign companies that only assemble their products in Brazil, without developing innovations locally.

**CHART 2**
China generates some energy from clean sources, but given the size of its economy the low carbon generation represents just a small part of the total. Manufacturing is the strongest part of its low carbon chart, since it produces most of the tools it uses domestically and export huge amounts of equipment, including solar panels and wind power material. In terms of innovation, China is catching up rapidly, though still not as productive as Korea.

GRAPH 3

Clean Energy: synopsis
Taiwan and Korea generate small amounts of energy from low carbon sources, but both have relevant manufacturing of low carbon technologies (mostly solar in Taiwan, and broader in Korea). Innovation is the strongest feature of the countries, with high levels of R&D and patents registered in low carbon technologies.

CONCLUSION

Flaunting a clean energy mix and favored by hydropower availability, abundant land for biomass and vast oil reserves, Brazil is not intensely encouraging clean and innovative energy technologies. The passive learning system forged during the country’s late industrialization hampers the efforts towards innovation, and the situation is hampered by an overvalued currency.

China, Taiwan and South Korea, on the other hand, endangered by the need to limit carbon emissions and reduce the vulnerability to energy imports, are adopting bold policies to foster clean technologies. The countries are favored by the active learning system that underpinned their industrialization and the depreciated currency that favors local manufacturing. Their energy policies reflect these different contexts.

Brazilian energy policies rely on imported technologies and bet on traditional sources of energy, resulting in a dependent energy industry, but a relatively clean energy mix. China, Taiwan and Korea adopted pro-innovation energy policies and are building a gradually autonomist low carbon energy industry. However, they still emit enormous amounts of greenhouse gases to supply their own energy needs.

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