Aluminium and GHG emissions: are all top producers playing the same game?

Lessons from existing empirical studies and policy implications

Yves Jégourel - Philippe Chalmin
Executive summary

The production of primary aluminium, whose industrial record can be traced back to the 1950s, is notoriously the world’s most energy-intensive industry, with red-light global warming potentials. Whereas historical producers have grounded their production in hydropower energy sources, “new comers” from the Gulf States, India and China, these days one the world’s leading producers, have effectively opted for fossil fuels (natural gas and coal) to power their smelters. Challenged by growing environmental concerns, the primary aluminium industry has undergone major changes over the last two decades to become a much more efficient industry with lower energy-intensity and GHG emissions during the smelting process. Antiquated smelters with low energy efficiency have been phased out, amperage cells have increased, alumina refining processes have been improved, and better control systems introduced to limit the so-called “anode effect”. As a result, the energy intensity required to produce one tonne of aluminium has steadily decreased over time, from a world average of nearly 17,000 kWh in 1980 to 14,289 kWh in 2014. From a lifecycle perspective, which encompasses mining to casting processes, the production of one tonne of aluminium ingot emits, on average, 16.5 CO₂e t, mainly carbon dioxide and fluorinated gases. There are however at least three reasons not to feel fully satisfied with the global aluminium picture. First, no let-up in coal use has been observed so far, despite the Chinese pledge to develop hydropower sources. Second, a great deal of uncertainty still hangs over the process of assessing the life cycle of greenhouse gas emissions. It would not have been a problem as such in that any evaluation is governed by the availability of data and methods employed to process them. But in the case of aluminium, the level of uncertainty is too high to be considered as a business-as-usual issue. Furthermore, it does seem important to extend the appraisal of the GHG-Aluminium nexus beyond the over-convenient “per tonne of aluminium” framework and to question the propriety of soaring Chinese production capacities by taking into consideration their heavy polluting power mix. Finally, one remains puzzled by the choice made by Chinese planners to develop aluminium production in China to the extent of becoming a net exporter and dragging world prices down- knowing the energy and environment dilemma facing the country. At the end of the day, the last kWh used to produce aluminium comes from coal!
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I. An overview of the primary aluminium world market

The legacy of the six “majors” – Alcan, Alcoa, Alusuisse, Kaiser, Pechiney and Reynolds – which once controlled the price of aluminium and often shaped the geographical distribution of mining and processing (i.e. refining, smelting and casting activities) seems to be over. The US giant Alcoa, the fourth largest primary aluminium producer in 2014 and one of the last survivors along with the Canadian Alcan (which was yet taken over by Rio Tinto in 2007) effectively decided to split its business into two publicly traded companies in the first half of 2016 to be better equipped to weather the global glut that has affected commodity markets for more than a year. The end of the so-called supercycle has indeed hit nearly all commodities and aluminium is no exception. As so often, the rout is due to the combination of plummeting demand in a context of languishing world economic growth and production overcapacities.

The onset of the aluminium era can be traced back to the 1950s when the drop in electricity costs, a key variable in the production process of this metal, helped to ensure its affordability for industrials, who gradually considered it to be a very attractive alternative to steel due to its interesting physical properties (lightness, strength at low temperature, good conductivity, resistance to corrosion). A sign of its greater affordability, American aluminium prices\(^1\) have indeed followed a marked downward trend, in constant 1998 USD and aside from periods of war or major geopolitical changes, from 14,000 USD at the beginning of the 20\(^{th}\) century to 1,500 USD in 2015. Over a shorter period of time and in nominal prices however, the picture appears to be rather different. Prices climbed, particularly at the end of the 1980s due to soaring demand from the transport equipment and building construction industries. The promises of a rosy future led companies, especially in China, to make massive investments not only in supply capacities but also in research and development to improve the aluminium production process. As a result of these increased production capacities, prices remained relatively low until the 2000s. With ever increasing demand and the growing influence of index traders and commodity trader advisors (CTA’s) on commodity financial markets, aluminium prices, along with nearly all base products, re-entered a marked upward trend starting mid-2003. After months of bullish trading, nominal prices went through the roof with a peak on the 11th of July 2008, when they approached 3,270 USD per metric ton (MT) on the London Metal Exchange (LME). Aside from the mid-1910s, when the onset of WWI saw historical highs (in constant USD), and May 1988, prices had never experienced a spike of this magnitude. This very substantial increase, still fuelled by strong domestic demand from emerging countries,\(^2\) led to a second increase in global supply capacities. According to the US Government Survey’s (USGS)\(^3\) long-term statistics (1900-2013), the world production of aluminium effectively hit a record of 47.6 million tonnes in 2013 and 48.41 million in 2014,\(^4\) which represents a year-on-year growth rate of nearly 5% over half of a century. Since 2000, 2009 was the only year, in the wake of the global financial crisis, to be marked by a significant decline of 6.30% in world aluminium production with large-scale uncertainty hanging over world economic growth as an economic backdrop. In that respect, it appears that the aluminium industry, as any capital intensive mineral industry, is characterized in the short run by relative inelasticity of supply.

\(^{1}\) US data from the USGS is the only long-term prices series available for minerals, but can be considered a good proxy of world prices, especially as far as aluminium is concerned.

\(^{2}\) While consumption from the BRICs accounted for 21.4% of world demand in 2000, it soared to more than 47% in 2010 (Nappi, 2013).

\(^{3}\) Open access data from the USGS is available on the following website: [http://minerals.usgs.gov/minerals/](http://minerals.usgs.gov/minerals/).

\(^{4}\) According to the IAI, the latest data available from the USGS being 2013.
A closer look at monthly data (01/1973-08/2015) from the International Aluminium Institute\(^5\) (IAI) shows that a substantial part of the primary aluminium production ramp-up was attributable to China. From January 1999 to July 2015, official Chinese aluminium production rose 14 times over to reach 2.7 million tonnes on a monthly basis (graph 2). While North American and Chinese producers accounted respectively for 27% and 10% of world production in January 1999, the balance of power has consequently been inverted in favour of China, which supplied 55% of world aluminium in 2014, i.e. 27,517 thousand metric tonnes out of 53,127 for the industry as a whole, against 4,585 for North American countries. The boom in the Chinese aluminium industry should not however mask a two-fold contrasted reality, where lower cost smelting unit capacities set in motion over the past few years dwarf the relative decline of older smelters.

A tremendous increase in supply should also be noticed with countries from the Gulf Cooperation Council (GCC: Saudi Arabia, Kuwait, the United Arab Emirates, Qatar, Bahrain, and Oman) since 2010 (the year when statistics become available). Production from these countries rose from 0.2 million in January 2010 to 0.43 million in August 2015, a 127% increase in five years (77% on a yearly basis from 2010 to 2014). In this respect, the production growth rate of the GCC countries has outpaced the Chinese figure over the last four years. As an indicator of this trend, it is worth noting that, among the ten biggest smelting units in the world, five are indeed now located in the Gulf region, especially in the United Arab Emirates (UAE),\(^6\) with production capacities ranging from 585,000 to 960,000 tonnes p.a. Although there is, to our knowledge, no comprehensive analysis on this subject, it appears that countries largely endowed with affordable fossil energy resources have exploited their comparative advantage to throw their hat into the ring and compete with historical producing

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\(^5\) Although the IAI considers this data as reliable (but subject to revision), its interpretation should not be overstated because some of the figures are estimates. For 2014, the IAI gauges total unreported production at 1.080 thousand metric tonnes, i.e. 2% of world supply. As far as China is concerned, unreported estimated production soared from 40 thousand metric tonnes in January 2008, the date from which statistics are available, to a level of around 293 thousand in 2013, i.e. nearly 7% of Chinese monthly production.

\(^6\) Jebel Ali (Dubal, UAE 960.000T/Y), Knuff (Aluminium Bahrain, Bahrain, 860.000T/Y), Abu Dhabi (Emirates Aluminium, UAE, 850.000 T/Y), Az Zabirah (Ma’aden, Saudi Arabia, 740.000T/Y) and Mesaieed (Qatalum, Qatar, 585.000T/Y). Source: Thomson reuters.
countries, either to meet their own domestic demand or to benefit from expected growing world demand for aluminium in the long term.

Graph 2: Geographical split of world aluminium production\(^7\) (kT, 1999-2015, monthly data)

The boom in Chinese aluminium production can also be observed with the leadership battle that has raged over the last decade between top world producing companies. In 2014, Aluminium Corporation of China, aka Chalco or Chinalco, has indeed been vying with the Russian Rusal to be the leading world producer of primary aluminium, while outputs from other Chinese companies such as China Power Investment Corporation, Hongqiao Group or Xinfa Group, have posted a significant rise over the last few years. It is also important to notice that Alcoa or Rio Tinto have kept their volume of production rather steady over the last few years, but the whip hand now held by the Chinese juggernauts, combined with the inescapable role of aluminium futures markets (on the LME and the Shanghai Futures Exchanges -SHFE), have put an end not only to the pricing power they once had but also to their ability to regulate the market through changes in quantity, i.e. via storage levels and a variation in their capacity utilization rates, to keep prices stable (Yang, 2002; Nappi, 2013). The relative strength of producing firms should however be interpreted with caution, as their competitive positions should also be considered not only over time, but also upstream (…) and downstream. According to the latest statistics from Thomson Reuters, China is, for instance, only the sixth largest bauxite producer, largely outpaced by Australia, Indonesia or Brazil, since local resources are verging on depletion and ore grades are declining\(^8\), with heavy dependence on imports. China has

\(^7\) According to the IAI, Total Aluminium is unwrought aluminium plus unprocessed scrap, metal in process and finished semi-fabricated (mill) products.

\(^8\) The bauxite grade, i.e. the percentage of aluminium oxide, partly determines the type of process that can be employed to refine bauxite into alumina. Moreover, it is worth noting that China has significant resources in diasporic bauxite (whereas
consequently to secure its supplies. At the tail end of the aluminium supply chain, it is also important to consider the competitive position held by each producer in the manufacturing segments ranging from the automotive and aerospace sectors to the beverage can or the building construction industries.

As with any commodity market, full understanding of price dynamics should not be limited to supply and demand drivers, as inventories, too, should be taken into account. In this respect, data from the IAI, although incomplete, indicates that stocks held by reporting producers, albeit in steady decline since 1999, have varied within a range of 1.2 to 1.55 million tonnes since 2010. They did however reach their two-year high in November 2014 (1.42 million tonnes). The increase in inventories can also be observed from the Shanghai Futures Exchange (SHFE) inventory volumes, which surged from 0.57 million tonnes in December 2013 to 0.88 in August 2015, but not on the LME where they hovered around 3.3 million tonnes, down from 5.5 million in mid-2013. Official inventories statistics for base metals should nonetheless not be over-interpreted, since not only some of the biggest producers, especially Chinese, are excluded from the IAI calculations, but also because stocks could similarly be held by physical traders or end-users, and not necessarily in the LME official warehouses. In this respect, the spread between the spot and three-month LME prices, *i.e.* the basis, could be a useful proxy to determine whether the physical market is in surplus or is suffering from shortage. All things being equal, the higher the level of the contango (backwardation), the higher (lower) the quantity of metals available in the market. It is clear from graph 4 that contango levels, which hit a five-year high in September 2013, have fallen sharply since then and even turned into a backwardation-type configuration at the end of 2014. This period of stress did not last long, however, as the market has shown, since January 2015, both rising contango levels and declining physical premium\(^9\) due to shorter delivery times for stocks. To that respect, it is worth noting that Japanese aluminium buyers recently secured a premium of 90USD per tonne for their fourth-quarter shipments, down from a record high of 425USD at the beginning of 2015, while US and European premiums went also down sharply to hover around 155USD and 120USD. As of September 2015, the market seems to be left with mixed feelings though. While rumours suggest that China may

90% of the world’s proven reserves are lateritic bauxites) which is not without consequence for both the process that can be employed to refine it into alumina, and the energy costs the latter entails.

\(^9\) LME cash prices cannot be equated with aluminium physical prices, due to physical delivery times. The physical premium can be hence defined as the price surcharge to be paid to obtain the metal from LME warehouses.
shed, per annum, around 2.4 million metric tons of aluminium smelting capacity before the end of 2015, they have been overshadowed by the fact that Chinese producers may increase their production capacity by 3.2 million metric tons, according to Antaike, a Chinese metal consulting agency. From an international perspective, the local supply and demand fundamentals of the Chinese aluminium market do have an overriding importance, not inherently as such but because of the rippling effects they produce on international prices.

![Graph 4: Contango/Backwardation on the LME](source: Datastream)

Akin to all major commodity markets with significant domestic trading, the analysis of primary aluminium market fundamentals should indeed distinguish between local supply and demand dynamics, and seaborne markets. In this respect, two major observations may be drawn from table 1 hereinafter.

<table>
<thead>
<tr>
<th>Year</th>
<th>Canada</th>
<th>China</th>
<th>Russian Federation</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2,386,643</td>
<td>389,347</td>
<td>3,293,908</td>
<td>-2,317,465</td>
</tr>
<tr>
<td>2011</td>
<td>2,354,293</td>
<td>432,974</td>
<td>3,319,102</td>
<td>-2,195,250</td>
</tr>
<tr>
<td>2012</td>
<td>2,263,468</td>
<td>-8,602</td>
<td>3,355,349</td>
<td>-2,326,018</td>
</tr>
<tr>
<td>2013</td>
<td>2,492,842</td>
<td>90,939</td>
<td>3,188,497</td>
<td>-2,381,510</td>
</tr>
<tr>
<td>2014</td>
<td>2,339,833</td>
<td>313,135</td>
<td>2,765,008</td>
<td>-2,543,187</td>
</tr>
</tbody>
</table>

Source: UNcomtrade

First, the Russian Federation and Canada appear to be the two biggest exporters of unwrought aluminium over the last four years, whereas the USA has constantly imported the product on a net basis. Second, owing to its formidable production capacities and fluctuating local demand, China has alternated between phases of net imports and exports. Thus, the country imported 8,602 tonnes in 2012 on a net basis, and exported almost 91,000 tonnes in 2013, i.e. a 1,157% increase in only one year, whereas the above mentioned countries saw their situation, be it as exporter or exporter, evolve by no more 13% (in absolute value) between 2010 and 2014. In 2014 for example, China was the only

10 That is exports minus imports. Re-imports and re-exports are not considered here.
country to increase its international exposure (a 244% surge in exports) whereas Canada and Russia reduced their exports and the USA its imports (see appendix, graph 12). This trend is further accentuated: in the first half of 2015, China exported 2.5 million tonnes of unwrought aluminium and aluminium products, with decreasing international prices and worldwide producers struggling to maintain their operational margins. As it can be seen from recent past history, understanding the Chinese export strategy, which is often a bone of contention with other ore or base metals exporters, has proved to be a delicate task. US aluminium producers have indeed alleged that Chinese producers have recently and deliberately exported “fake semis”, i.e. semi-fabricated aluminium products\(^{11}\) that are re-melted or stockpiled so as to evade the tax levied on primary aluminium exports and obtain the VAT refund on transformed products\(^{12}\). However, this situation is not new. As detailed by Schwartz and Hodum (2011), the Chinese government reduced VAT rebates on primary aluminium exports in 2004 (and even cancelled them later on) in order to limit incentives for overproduction. Aluminium producers did not see it this way and started to transform their products so as to remain eligible for this tax relief. This triggered a cat-and-mouse game which prompted the regulator to further reduce the tax base of a mechanism that has proven to be ineffective. It can indeed be observed from table 2 below that, according to the UNcomtrade data, the share of unwrought aluminium in total aluminium exports for China fell from almost 42% in 2000 to 13% in 2014, whereas the exports of plates, sheets, strips and foils soared to represent more than one half of total Chinese aluminium exports. Most observers and participants agree that the Chinese overcapacities and the resulting increase in exports of aluminium semi-finished products have exacerbated the current glut on the international market. As summarized by the World Bank (2015, p. 26), “the market outside China remains in deficit because of smelter closures, but China’s smelting capacity continues to expand, resulting in a global surplus”.

**Table 2: Aluminium export structure for China**

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unwrought aluminium.</td>
<td>41,84%</td>
<td>20,46%</td>
<td>13,10%</td>
</tr>
<tr>
<td>Waste and scrap.</td>
<td>1,51%</td>
<td>0,03%</td>
<td>0,02%</td>
</tr>
<tr>
<td>Powders and flakes.</td>
<td>0,12%</td>
<td>0,14%</td>
<td>0,20%</td>
</tr>
<tr>
<td>Bars, rods and profiles.</td>
<td>12,80%</td>
<td>15,97%</td>
<td>16,79%</td>
</tr>
<tr>
<td>Wire.</td>
<td>0,44%</td>
<td>0,35%</td>
<td>0,44%</td>
</tr>
<tr>
<td>Plates, sheets and strips, of a thickness exceeding 0.2 mm.</td>
<td>6,16%</td>
<td>24,62%</td>
<td>34,16%</td>
</tr>
<tr>
<td>Foil</td>
<td>4,97%</td>
<td>12,94%</td>
<td>17,05%</td>
</tr>
<tr>
<td>Tubes and pipes.</td>
<td>1,41%</td>
<td>2,06%</td>
<td>3,03%</td>
</tr>
<tr>
<td>Tube or pipe fittings</td>
<td>0,11%</td>
<td>0,37%</td>
<td>0,41%</td>
</tr>
<tr>
<td>Structures and parts of structures</td>
<td>12,78%</td>
<td>10,89%</td>
<td>0,00%</td>
</tr>
<tr>
<td>Reservoirs, tanks, vats and similar containers</td>
<td>0,02%</td>
<td>0,02%</td>
<td>0,03%</td>
</tr>
<tr>
<td>Casks, drums, cans, boxes and similar containers</td>
<td>2,01%</td>
<td>0,67%</td>
<td>0,50%</td>
</tr>
<tr>
<td>Containers for compressed or liquefied gas.</td>
<td>0,00%</td>
<td>0,13%</td>
<td>0,12%</td>
</tr>
<tr>
<td>Wire, cables, plaited bands and the like, of aluminium, not electrically insulated.</td>
<td>0,98%</td>
<td>2,35%</td>
<td>3,08%</td>
</tr>
<tr>
<td>Table, kitchen or other household articles and parts thereof.</td>
<td>7,11%</td>
<td>0,00%</td>
<td>0,00%</td>
</tr>
<tr>
<td>Other articles of aluminium.</td>
<td>7,74%</td>
<td>9,91%</td>
<td>11,06%</td>
</tr>
</tbody>
</table>

\(^{11}\) Especially heavy-gauge aluminium extrusions, plate and cast coil, which require minimum semi-fabrication transformation.

\(^{12}\) “Aluminum industry body asks U.S. authorities to probe China exports”, Reuters, September 17, 2015.
II. Production, electricity cost and GhG emissions: the staple triptych of primary aluminium

The primary aluminium industry is notoriously energy-intensive and even ranks among the world’s most energy-intensive industries. As a rule of thumb, four to five tonnes of bauxite will provide two tonnes of alumina, which will in turn be transformed via electrolysis into one tonne of aluminium at an actual average energy cost of 14,000 kWh. Owing to the smelting process, to the power generation that it requires and to many others supporting processes, the aluminium industry has been identified as a major contributor to GhG emissions and is therefore under particular scrutiny from the Intergovernmental Panel on Climate Change (IPCC), one of whose targets is to reduce these emissions by 50 to 85% by 2050.

II.1. Aluminium production technology in a nutshell

Transforming alumina into aluminium requires electrolysis, according to the Hall-Heroult process invented in 1886. Whereas the process for making alumina has barely changed since its invention, the same cannot be said for aluminium smelting. Two main technologies, known as Söderberg and Prebake (PB), are employed for this process, depending on the type of anode that is used. Succinctly, alumina is reduced into aluminium using cells (also commonly called pots) where an anode, made with coke or graphite and coal-tar pitch used as a binder agent, is combined with a cathode that is found in the carbon lining of the large steel container located under the anode. The electrolyte, which requires large quantities of electrical power, is made with an alumina/cryolite solution and with ancillaries, such as aluminium fluoride and calcium fluoride. The bath is heated to 980°C which allows molten aluminium to deposit at the cathode while oxygen reacts with oxidation at the anode to form carbon dioxide.

The main technical difference between Söderberg and PB concerns the type of anode that is employed. Söderberg uses a continuous anode added as a paste and baked in the cell, whereas the more modern Prebake technology relies on multiple anodes in each cell that are connected in series (potline). As their name implies, these carbon blocks are baked in separate baking furnaces. There are in fact many different types of PB technologies, depending on how the alumina is introduced into the cell, from centre-work prebake (CWPB) or side-work PB (SWPB) to the state-of-the-art point-feed PB (PFPB). Technological developments have also led to an increase in the cell’s amperage from 50kA to 400kA, with an improvement in productivity as a direct consequence. Indeed, the quantity of aluminium produced per unit time primarily depends on the average current going through the cell during that time. This smelting process is continuous, meaning that any unexpected power supply disruption for more than few hours may lead to severe damage insofar as the liquid aluminium will solidify in the pots.

The type of technology that is employed to reduce alumina has an overriding impact on both energy consumption and greenhouse gas (GHG) emissions. Regarding energy consumption, the Söderberg technology requires much more electricity than PB and as a result has been steadily phased out. According to IAI statistics, only 3,126 million tonnes of primary aluminium were produced in 2014 using this process. Whatever the technology, most aluminium smelters are equipped with their own captive power plants to meet the huge power requirement, which explains why historically they have been located near abundant energy sources, especially hydropower plants.

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13 Three processes can be employed: Sinter, Bayer-Sinter, and Bayer, the latter being the least energy-intensive.
14 Two Söderberg technologies may also be considered: horizontal stud and vertical stud.
15 Mainly carbon dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O) and fluorinated Gases (Hydrofluorocarbons, -HFC and PFC- and sulphur hexafluoride (SF₆)).
It is evident from graph 5 that the energy intensity required to produce one tonne of aluminium has steadily decreased over time, from a world average of nearly 17,000 kWh in 1980 to 14,289 kWh in 2014. According to IAI 2014 statistics, China has the lowest energy cost (13,596 kWh), representing a decrease in smelting energy intensity of 18% in less than twenty years (versus a world average of 10%). Obviously, this “lower energy intensity” effect should not conceal the fact that energy consumption has picked up over the last decade, along with primary aluminium production.

Table 3: Power mix and source of primary aluminium production\(^{16}\) (GWh\(^{17}\), 2014)

<table>
<thead>
<tr>
<th>POWER MIX</th>
<th>North America</th>
<th>Asia (ex China)</th>
<th>Europe (incl. Russia)</th>
<th>GCC</th>
<th>China</th>
<th>Estimated Unreported</th>
<th>World Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>ND</td>
<td>213,884</td>
</tr>
<tr>
<td>Coal</td>
<td>47,646</td>
<td>546</td>
<td>95,382</td>
<td>0</td>
<td>37,413</td>
<td>ND</td>
<td>400,572</td>
</tr>
<tr>
<td>Oil</td>
<td>8,621</td>
<td>15,797</td>
<td>6,852</td>
<td>0</td>
<td>336,714</td>
<td>ND</td>
<td>956</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>277</td>
<td>0</td>
<td>335</td>
<td>28</td>
<td>0</td>
<td>ND</td>
<td>66,748</td>
</tr>
<tr>
<td>Nuclear</td>
<td>578</td>
<td>0</td>
<td>2,810</td>
<td>57,640</td>
<td>0</td>
<td>ND</td>
<td>8,010</td>
</tr>
<tr>
<td>Total</td>
<td>57,129</td>
<td>16,343</td>
<td>113,279</td>
<td>57,668</td>
<td>374,127</td>
<td>80</td>
<td>690,170</td>
</tr>
<tr>
<td>POWER SOURCE</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td></td>
</tr>
<tr>
<td>Self-Generated</td>
<td>22,107</td>
<td>16,108</td>
<td>9,622</td>
<td>57,365</td>
<td>224,476</td>
<td>ND</td>
<td>337,295</td>
</tr>
<tr>
<td>Purchased</td>
<td>35,022</td>
<td>235</td>
<td>103,657</td>
<td>303</td>
<td>149,651</td>
<td>ND</td>
<td>352,875</td>
</tr>
<tr>
<td>Total</td>
<td>57,129</td>
<td>16,343</td>
<td>113,279</td>
<td>57,668</td>
<td>374,127</td>
<td>80</td>
<td>690,170</td>
</tr>
</tbody>
</table>

Source: IAI

\(^{16}\) Oceania, South America and Africa are not reported in this table but taken into account into « world reported ».

\(^{17}\) Giga watts per hour.
As illustrated by graph 6 below, China is, as far the production of primary aluminium is concerned, by far the largest user of coal for power generation, with an ever increasing demand for this heavily polluting fuel, whereas other countries (or groups thereof) have reduced consumption or kept levels unchanged. Almost 90% of the total power required to produce Chinese primary aluminium, i.e. 336,714 GWh out of 374,127, is based on coal-fired energy, making this fossil fuel the most widely used energy in the world’s aluminium industry, far ahead of hydropower 213,884 (GWh) or natural gas (66,748). It is worth noting that according to IAI data, the Chinese power mix has not changed since 1995. GCC countries, whose aluminium production has also soared over the last decade, rely entirely on natural gas, whereas North America and Europe employ mainly hydropower plants. In the case of North American countries, the power mix has evolved significantly since 1980. At that time, 52% of the electricity required was hydro-generated, versus 83% in 2014, with a decreasing share for coal, down from 31.58% to 15.09%. European countries have followed almost the same pattern with a 74% decrease in reliance on coal. To our knowledge, no comprehensive analysis has been undertaken to explain these trends, but it does not seem unreasonable to assume that it has been driven in Western countries by both the enforcement of stricter environmental laws and, more pragmatically, by economic reasons tied to energy prices and the will to reduce energy dependency.

Owing to its huge energy demand and depending on the type of fuel that is employed to generate it, the production of aluminium results in substantial direct and indirect GHG emissions and, to a much lesser extent, in the release of fluorides. The global primary aluminium industry was estimated to be responsible for 1% of global GHG emissions in 2008 (IEA, 2009). As shown in figure 1 below, both carbon dioxide (\(\text{CO}_2\)) and PFC\(^{18}\) may be generated. Five main different anthropogenic sources of direct \(\text{CO}_2\) emissions are now recognized: fuel combustion in furnaces or boilers, coke calcination, anode

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\(^{18}\) perfluorocarbons.
production and consumption, and lime production (IAI, 2006). PFC is emitted from anode consumption. It is clear that indirect GHG emissions, i.e. emissions that do not directly originate from the production process, meaning transport and power generation for bauxite and alumina, should also be taken into account. If the evaluation of GHG emissions is a matter of absolute necessity, it is in the meantime worth noting that this task encounters a number of hurdles related to the nature of available data, and to the methods that are adopted (Zhang et al., 2015). As shown by the “Aluminium sector greenhouse gas protocol” (IAI, 2006), carrying out such a comprehensive undertaking is a particularly complex task whose results should therefore be interpreted with caution and linked to the underlying assumptions that have been used to reach them.

**Figure 1: Aluminium stages of production and GHG emissions**

II.2. Carbon dioxide and other GHG emissions

As far as the smelting process is concerned, three main causes of carbon dioxide emissions can be identified. The largest proportion of CO₂ emissions results from the formidable consumption of electricity used in electrolysis. As of 2004, it accounted for 59% of GHG released during the smelting process (see Table 3). Obviously, this figure can only be used for indicative purposes insofar as the source of power generation has an overriding impact not only on carbon emissions but also on the degree of uncertainty that surrounds the methods used to identify and calculate GHG emissions. In this regard, significant discrepancies between countries can be observed in the power mix used to generate electricity.

The amount of CO₂ produced when a fuel is burned is a function of the carbon content, coal being the most polluting energy. According to the IEA’s latest indicative statistics, the amount of CO₂ per kWh effectively ranges from 0.94 to 0.98 kg for coal (depending on its composition and the type of combustion), whereas natural gas-fired plants emit 0.54 CO₂ per kWh. Hydroelectric or nuclear plants do not, on the contrary, emit significant levels of CO₂. Assuming that the world’s average energy requirement of 14,289 kWh holds, the CO₂ emissions per tonne of aluminium due to electricity consumption can vary, for 1 tonne of aluminium, from 7.7 tonnes, if natural gas is used, to 14 tonnes for lignite.

A second major source of CO₂ stems from the carbon anode reaction with alumina and diverse sources of oxygen. As far as PB technology is concerned, anode manufacturing will also be responsible for these emissions. The baking of the so-called “green anode” indeed favours gas emissions as baking furnaces are fired by fossil energy. Additionally, coke calcination that is needed to produce these anodes is also a potential source of CO₂ akin to the oxidation of the packing coke that covers the anode, and to the combustion of volatile components from the pitch binder. Finally, soda ash releases gases as well, when added to the electrolysis.

Smelting and anode production are not, however, the only causes of carbon dioxide emissions, which also result from the combustion of fossil fuels required not only to extract and transport bauxite by
land and sea to alumina refineries, but also to refine alumina. Lime or calcium oxide, which may be employed to remove silicates before the smelting process of metals such as steel, or to manufacture chemicals, is often a by-product of aluminium production, but will generate carbon dioxide.

Table 4: GHG emissions per production process (2004)

<table>
<thead>
<tr>
<th>Bauxite</th>
<th>Refining</th>
<th>Anode</th>
<th>Smelting</th>
<th>Casting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>0</td>
<td>0</td>
<td>45.70%</td>
<td>16.61%</td>
</tr>
<tr>
<td>Electricity</td>
<td>0</td>
<td>5.85%</td>
<td>7.42%</td>
<td>59.25%</td>
</tr>
<tr>
<td>Fossil Fuel</td>
<td>33.33%</td>
<td>79.51%</td>
<td>15.90%</td>
<td>1.36%</td>
</tr>
<tr>
<td>Transport</td>
<td>66.67%</td>
<td>6.16%</td>
<td>0.94%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Ancillary</td>
<td>0</td>
<td>4.48%</td>
<td>30.04%</td>
<td>0</td>
</tr>
<tr>
<td>PFC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22.74%</td>
</tr>
<tr>
<td>Total (kg)</td>
<td>48</td>
<td>991</td>
<td>849</td>
<td>9.789</td>
</tr>
<tr>
<td>Per tonne Al</td>
<td>248</td>
<td>1.908</td>
<td>374</td>
<td>9.789</td>
</tr>
</tbody>
</table>

Source: Bergsdal et al. (2004)

Along with CO₂ emissions, the smelting process will produce the release of two PFC compounds: tetrafluoromethane (CF₄) and hexafluoroethane (C₆F₁₃). Called the “anode effects”, the emission of PFC does not occur under normal operating conditions but is triggered when the level of alumina in the bath drops below 2%, an event that will halt the aluminium production process and increase the cell’s voltage, together with GHG discharges. The rapidity with which alumina can be fed into the pots to restore operating levels is consequently a key variable to stop these anode effects. As for carbon emissions, the level of PFC emission will therefore be highly dependent on the smelting technologies that are used, but also on the effectiveness of control systems. Considerable efforts have been deployed by aluminium producers in this respect.

Table 5: PFC emissions per type of technology (2014)

<table>
<thead>
<tr>
<th>production (kt Al)</th>
<th>CF₄ (Gg)</th>
<th>C₂F₆ (Gg)</th>
<th>PFC (kt CO₂e)</th>
<th>Global Mean PFC emissions intensity (t CO₂e/t Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWPB</td>
<td>3,584</td>
<td>0.055</td>
<td>0.007</td>
<td>487</td>
</tr>
<tr>
<td>PFPB (Non China)</td>
<td>18,361</td>
<td>0.539</td>
<td>0.071</td>
<td>4,854</td>
</tr>
<tr>
<td>PFPB (China)</td>
<td>27,517</td>
<td>2.752</td>
<td>0.127</td>
<td></td>
</tr>
<tr>
<td>SWPB</td>
<td>539</td>
<td>0.255</td>
<td>0.064</td>
<td>2,668</td>
</tr>
<tr>
<td>HSS</td>
<td>102</td>
<td>0.031</td>
<td>0.003</td>
<td>269</td>
</tr>
<tr>
<td>VSS</td>
<td>3,024</td>
<td>0.422</td>
<td>0.057</td>
<td>3,815</td>
</tr>
<tr>
<td>All Techs</td>
<td>53,127</td>
<td>4.054</td>
<td>0.329</td>
<td>33,974</td>
</tr>
</tbody>
</table>

Source: IAI

As shown in table 5 above, PFC emissions in 2014 ranged from 4.95 t CO₂e/ per ton of aluminium for SWPB smelters to as low as 140 kg CO₂ for CWPB technology, with an average (taking all technologies into consideration) of 640 kg. It is important to note that a number of statistical discrepancies may be observed when comparing with other sources. There are several reasons for this, but one major point is that the conversion factors used to convert grams of PFC into their CO₂ equivalent (CO₂e) have changed since 2013. The 2007 IPCC Fourth Assessment Report has indeed revised Global Warming Potential (GWP) values of these PFC. Previously estimated at 6,500 for CF₄ and 9,200 for C₂F₆, they have now been increased to respectively 7,390 and 12,200. At all events, a

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19 i.e. diesel oil and residual fuel with high sulphur content (or distillate fuel to a lesser extent) for maritime transport.
20 The Bayer process does not directly generate CO₂.
21 Carbon dioxide equivalent (CO₂e) emissions are calculated by multiplying the total tonnage of each PFC component gas by the Global Warming Potential (GWP) values reported in the IPCC 4th Assessment Report.
huge decrease in PFC emissions is evident. The 1990 global mean intensity of PFC emissions was equal to 5.06t CO2e/t Al, representing a 87% drop in 24 years.

Graph 7: Global PFC emissions and intensity (1998-2014)

As a result, while primary aluminium production has soared by more than 133% since 1998, global PFC emissions have tumbled by 51% over this same period, from 70,000 kT CO2e to less than 34,000 in 2014.

The smelting process will ultimately generate two types of gaseous and particulate fluorides, hydrogen fluoride, as well as sodium and aluminium fluorides (F-). F are one of the most phytotoxic air pollutants released by the metal industries, including aluminium smelting, which can cause direct damage\(^{22}\) to plants and trees in the vicinity of emission sources and consequently to mammalian herbivores. Albeit emitted during the smelting process, given that aluminium fluoride and calcium fluoride are added to the cryolite to lower the electrolyte’s freezing point\(^{23}\), fluorides do not belong to the GHG category.

\(^{22}\) The level of pollution intensity is also determined by topography, soil type, and the direction of prevailing winds (Arnesen et al., 1995).

\(^{23}\) A fraction of the aluminium fluoride added to the bath is indeed lost through volatilization, when the temperature increases.
Table 6 : Fluoride emissions per electrolysis technology (2014)

<table>
<thead>
<tr>
<th></th>
<th>Reported production (kT Al)</th>
<th>Reported Tot. F. Emissions (kT F)</th>
<th>Aluminium Production (kT Al)</th>
<th>Fluoride Emissions (kT F)</th>
<th>Mean F. Emissions Intensity (kg F/t Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>15,123</td>
<td>20</td>
<td>50,001</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>Soderberg</td>
<td>1,664</td>
<td>5</td>
<td>3,126</td>
<td>6</td>
<td>2.05</td>
</tr>
<tr>
<td>PB + Soderberg</td>
<td>16,787</td>
<td>25</td>
<td>53,127</td>
<td>46</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Source: IAI

According to IAI data, fluoride emissions have considerably dropped over time to reach 0.8 kg per tonne for PB and 2.05 for Söderberg technology in 2014, down from 2.07 and 3.01 in 1990. Major improvements in control and recycling systems explain the reduction. In this respect, these emissions no longer seem to be included among the environmental issues associated with primary aluminium, at least under normal conditions of production. Admittedly, as recent studies have shown (Brougham et al, 2013), excess fluoride concentrations can also be found after the active smelting period, but the effects have proven to be short-lived and will consequently not be given any further consideration in this report.

What are, then, the global consequences in terms of CO₂e of producing one tonne of aluminium ingot? As of 2010 (table 7 below), the IAI (2014) suggests that on average 16.5 tonnes of CO₂e will be emitted, of which 55% for electricity for a large part related to electrolysis.

Table 7: Life-cycle assessment of GHG emissions of aluminium production processes (CO₂e/kg Al)

<table>
<thead>
<tr>
<th></th>
<th>Bauxite mining</th>
<th>Alumina Refining</th>
<th>Anode production</th>
<th>Electrolysis</th>
<th>Casting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>&lt;0.1</td>
<td>9.2</td>
<td>&lt;0.1</td>
<td>9.7</td>
</tr>
<tr>
<td>Process &amp; Auxiliary</td>
<td>&lt;0.1</td>
<td>0.7</td>
<td>0.4</td>
<td>2.3</td>
<td>&lt;0.1</td>
<td>3.5</td>
</tr>
<tr>
<td>Thermal energy</td>
<td>&lt;0.1</td>
<td>2.2</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Transport</td>
<td>0</td>
<td>0.5</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>Total</td>
<td>&lt;0.1</td>
<td>3.8</td>
<td>0.6</td>
<td>11.9</td>
<td>0.2</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Source: IAI (2015)

III. Beyond statistics: the half-hearted environmental achievements of the primary aluminium industry

The progress achieved over the years in lowering the energy-intensity of aluminium production may doubtless be seen as a rather remarkable example. However, whether a clean bill of health can be given to the world industries of primary aluminium, particularly in China, remains a moot point. There are at least three reasons not to feel satisfied with the global aluminium picture and, as a matter of consequence, to raise questions over Chinese achievements, as Chinese producers supplied 55% of world aluminium in 2014 and have recently emerged as an important player in global markets.

- First, as previously mentioned, the power mix used by Chinese smelters relies heavily on coal, the most polluting fossil fuel, and so far no let-up in its use has been observed. In this respect, the technological improvements detailed above should be put in perspective.

- Second, a great deal of uncertainty still hangs over the process of assessing the life cycle of greenhouse gas emissions. It would not have been a problem as such in that any evaluation is governed by the availability of data and methods employed to process them. But in the case of aluminium, the level of uncertainty is too high to be considered as a business-as-usual issue.
Finally, it does seem important to extend the appraisal of the GHG-Aluminium nexus beyond the over-convenient “per tonne of aluminium” framework and to question the propriety of soaring Chinese production capacities by taking into consideration their heavy polluting power mix.

III.1. Towards a state-of-the-art Chinese aluminium industry

The skyrocketing course of Chinese aluminium groups did not come out of the blue and has largely benefited from diverse and varied initiatives undertaken by central authorities to promote their competitiveness. From this point of view, the tremendous efforts that have been made and their resulting achievements in less than two or three decades should be saluted. Back in the 1980s, China’s aluminium industry was indeed grounded in small-scale and rather inefficient producers. Since 1992, the country’s industrial policy has evolved dramatically to spur holistic market-oriented reforms that have favoured competition between producers and the quest for economies of scale. As underlined by Rock & Toman (2015), the shut-down of small aluminium producers was meant to boost the competitiveness of state-owned enterprises to a prevalent economic backdrop of China opening up to world markets and surging local demand. In the case of aluminium, one of the main goals was to mothball antiquated Söderberg-type smelters, to encourage mergers and acquisitions and vertical / horizontal integration in search of the “optimal industrial size”, and to promote state-of-the-art plants. As an example to gauge how far the Chinese industry has come, it is interesting to remember that Chinalco, now the first or second most prolific world producer, did not figure amongst the top ten producers back in 1995 and was ranked only ninth in 2003 with a meagre market share of 2.3%, versus 12.4% for the US Alcoa (Bergsdal et al. 2004).

To ensure that the industry fell in with such a major transformation, the development of new smelters with production capacities lower than 100,000 metric tons per year were prohibited after 2003, and technological upgrades towards lower energy intensity requirements were either prompted or imposed, in favour not only of PB technologies but also of greater amperage. More stringent energy efficiency norms in particular were enforced in 2008 which fixed, for newly built smelters, a maximum required energy intensity of 14,300 KWh per tonne of aluminium ingot or 13,800 KWh per tonne for smelting, which were lower than international standards. According to the notice of February 22, 2008 from the National Development and Reform Commission (NDRC) and the State Electricity Regulatory Commission, preferential power pricing policies afforded by Chinese local government to aluminium producers to foster the development of local producing units were also abandoned from 2009 onwards (Schwartz & Hudam, 2011), with the search for greater energy efficiency being a direct consequence. From this point of view and according to the huge level of power costs in the aluminium process, it is important to highlight the fact that the reform of its electricity market, and the resulting effective electricity paid by smelters, have long been perceived by Beijing as a way to influence the structure of its own aluminium producing sector. Along with the VAT rebates system, the pre-2009 situation in China is probably not unrelated to the country’s current oversupply, which is pulling down international prices.

The offensive did not solely target primary aluminium producers, it hit the whole supply chain and, effectively, all the energy-intensive industries in China from cement to steel. Intensive research and development efforts have for example been carried out to improve process to refine high-silica bauxite with which China is largely endowed. As stated by Zhang et al (2015), the lime-soda sinter and the sinter-Bayer combination processes that were largely used prior to 2005 require more energy intensive
than the traditional Bayer process employed for lateritic bauxite\textsuperscript{24}. In order to reduce both its economic and environmental costs, heavy R&D investments have consequently been made and led to the setting up of the lime Bayer process, which, in itself, also helps to limit the environmental impacts of the primary aluminium supply chain.

### III.2. Estimations caveat

As shown by the considerable work accomplished by the IAI, assessing the GHG emissions of primary aluminium production has proved to be very difficult and is, like any evaluation procedure, highly dependent on the system’s boundaries (number and type of production process considered, type of GHG, coverage of transport and auxiliary procedures), the availability and quality of data and, finally, on the methodology that is employed to process them. Inevitably exposed to a certain degree of residual imprecision due to the reporting process, analyses based on individual plant-level data provide the most accurate results but are, for obvious reasons, nearly impossible to carry out on a full worldwide or even a country scale. In this respect, analyses which calculate global CO\textsubscript{2}e emissions by considering each production process and taking into account the average “per unit” CO\textsubscript{2}e emissions are usually favoured by researchers and international aluminium associations such as the IAI.

One of the latest pieces of research on this subject, carried out by Zhang \textit{et al} (2015), considers for example the specific energy consumption of each alumina refining process, based on a given proportion – from national surveys results – of these processes in the total outputs of Chinese alumina, and then estimates the average CO\textsubscript{2} levels emitted during this production stage. A similar approach is taken for the smelting and casting processes: the power mix and the type of electrolysis used by smelters are, for instance, considered on a regional basis to calculate their respective emissions which are in turn used to estimate the national weighted average of CO\textsubscript{2} emissions for Chinese ingot production, i.e. 14.972 kg (per kg of aluminium ingot). As mentioned above, the sensitivity analysis led by these researchers shows that a degree of inaccuracy, ranging from +/−0.2\% for the anode consumption process to -12.5/8.3\% for coal combustion, has to be accepted. Depending on their methodology, their scope and, naturally, their date of completion, various levels of CO\textsubscript{2} and CO\textsubscript{2}e can consequently be obtained. Also published in 2015, the article written by Hao \textit{et al} (2015) suggests for instance that these emissions could be higher on a national basis, i.e. 16.5kg, with very significant regional disparities, from 8.2kg of CO\textsubscript{2}e for Qinghai province to 21.7 for Inner Mongolia. These two assessment methods (individual plant-level data/industry typical values) are of course not mutually exclusive and may be combined, as recommended in the IAI Aluminium sector greenhouse protocol (2006).

Questioning the relevance of methodological choices made to carry out the above mentioned analyses is far beyond the scope of this report. Nevertheless, two observations can and should be made. First, while a certain degree of uncertainty is fully legitimate, it is on the contrary more complicated to understand what appears to be a growing reluctance from Chinese producers to fully respond to IAI surveys that still provide the data needed to estimate worldwide GHG emissions for the primary aluminium industry. The global life cycle inventory data report released in August 2013 is indeed based on improper Chinese data using an excessive degree of aggregation. As stated in this report, “with respect to the inventory’s characterization of the global industry’s inputs and outputs, the greatest obstacle to the achievement of this goal is the lack of Chinese industry data reported in a quality high enough for inclusion in the database” (P. 21). It could be claimed however that the rigorous scientific articles produced on the GHG impact of the Chinese aluminium industry partly fill this gap, but what we still lack is a unified and generally accepted framework to assess GHG emissions on a worldwide basis. This is precisely what the IAI initiative intends to achieve. Second, whereas a great deal of attention

\textsuperscript{24} The efficiency of alumina extraction depends on the digestion process which in turns is linked to bauxite mineralogy. For gibbsitic bauxite, this process requires relatively low temperatures, which is not the case for bohemitic and diasporic bauxites, thereby inducing higher energy costs.
has been given to evaluate GHG emissions during the alumina refining and smelting processes, it is not sure whether bauxite mining and transportation\textsuperscript{25} have been considered accordingly. In the light of the 2014 Indonesian ban on unprocessed ore which prompted Beijing to shift its imports towards Guinea, improved gauging of the impact of maritime transport of bauxite on GHG emissions would seem to be of considerable importance.

\section*{III.3. The Chinese conundrum}

The major technological breakthrough obtained by world aluminium producers, foremost among them the Chinese operators, should not overshadow the existence of recurrent oversupplies in international markets and the unavoidable question of the key drivers of Chinese production levels. In this respect, the statement made by Schwartz and Hodrum (2010) is explicit: “An important part of the drive to wrestle energy and environmental savings from the Chinese aluminium industry is reining in the chronic over-capacity that exists in the industry, which in turn has resulted in such irrational (from a macroeconomic, energy and environmental standpoint) behaviour as exports of primary aluminium”

\begin{figure}
\centering
\includegraphics[width=\textwidth]{graph8.png}
\caption{Chinese aluminium production and coal consumption}
\end{figure}

Although the reliance on coal for alumina refining has globally decreased (IAI, 2013), graphs 6 and 8 clearly indicate that Chinese aluminium production is highly correlated to the use of coal, with no explicit signs of such use being curbed over the last decade. This raises two important questions. First, to what extent should technological breakthroughs achieved by China be put on the credit side of an ambitious environmental policy or should they, on the contrary, be understood as a tool to mitigate the environmental impacts of ever-increasing production capacities? Second, it appears crucial to question, as mentioned earlier, the rationality of Chinese aluminium producers. In others words, can this increase in production capacity be fully explained by a corresponding surge in demand for aluminium products?

\textsuperscript{25} It is worth noting here that this accounts for over 80\% of world trade by volume and for approximately 3\% of global greenhouse gas emissions.
As for the first question, no-one could deny that China has officially taken the necessary steps to wean itself off fossil fuels. The country, which is already the biggest hydro-power producer, has effectively opted in its five-year plan for 2011-2015 to raise total hydro-power capacity from 220 GW to 290 GW. This goal has almost been reached with a capacity of 282 GW at the end of 2014. By the same token, Li Keqiang, the Chinese prime minister reaffirmed in 2014 his determination to double China’s capacity by 2020. Although major projects are consequently expected to be put in motion, experts still doubt whether this goal could be achieved. There are several reasons for this. As stated by Xingang et al (2012), financial constraints due to the persistence of small-scale enterprises could in particular hinder the development of a sector that has still to cope with a decrease in local demand for power due to worsening local economic conditions. As of 2012, the latter appeared indeed to be piecemeal with China’s 45,000 small hydro-power stations belonging to 20,000 enterprises. Regardless of intrinsic hydro-power potential in China, it has still to be demonstrated that the country will modify the power mix of primary aluminium producers. Power generation is not power distribution, and efficient energy transmission infrastructures linking remote supply centres to industrial areas are still to be developed. The complex ownership structure of power plants, alternately controlled by central and provincial governments, appears to be a major hurdle to this strategy. In this respect and until the electricity market is reformed, based on the “Direct Purchase for Large Users” measure, it is most unlikely that the global reliance of primary aluminium producers on coal will change radically in the medium term. Besides, one of the most compelling and simplest signs of evidence for this is that the power mix of Chinese aluminium production has not evolved despite the country’s growing hydropower capacity. A second way to apprehend the Chinese pledge towards better environmental practices is to consider the key drivers of Chinese aluminium production and its global impact on GHG emissions, rather than reasoning on “per unit” basis. As stated on the IAI website, “while primary aluminium production more than doubled over the period 1990 – 2010, total direct greenhouse gases from the production process increased by only 20%”. As indisputable as this assertion is, it is indeed worth questioning the rationality behind such an increase in Chinese production. Although a moot point, this ultimately leads us to an economic perspective, to measure to what extent this production reacts to price signals. To do so, we have developed a very simple VAR (Vector Auto-Regressive Model) econometric model, based on IAI monthly production data, from January 99 to July 15.

26 With the Three Gorges plant on the Yangtze River accounting for 22.5 GW of capacity.
29 http://primary.world-aluminium.org/aluminium-facts/greenhouse-gases.html
30 In a nutshell, a VAR is an econometric model whose ambition is to characterize the relationships between a given set of variables and their past value.
31 Owing to its severe limitations, this model should be considered for illustrative purpose rather than for its intrinsic scientific interest. The technical aspects of this model are not presented here, but are available on request.
Despite its simplicity, this category of model provides a graphic representation of the sensitivity of given variables to shocks affecting other variables. Under this model, we thus consider to what extent primary aluminium production is affected by changes in LME cash and three-month aluminium prices. As shown by graph 9, it is clear to see that China aluminium production (i.e. the LN_CHINA variable) does not seem to fully respond, quite the opposite, to market price signals (LN_PRICE CASH and LN_PRICE_3M), whereas production from Western Europe (LN_WESTEUR) and North America do. There could be numerous explanations for this, from model misspecifications to economic reasons. Of these, two should be highlighted, both non-mutually exclusive. First, as mentioned above, Chinese smelters, prior to 2009, benefited from distorted electricity prices and R&D incentives which, most probably, had lasting effects. The build-up of the competitive advantages induced by these public policies have increased their resilience to downward prices and, consequently, their capacity to maintain production levels, whatever the market conditions. Second, we cannot rule out the possibility that these Chinese producers, implicitly encouraged by the changing nature of the country’s export policies (see p. 9), have adopted a common non-cooperative attitude towards their international competitors, one that is precisely grounded in these comparative advantages.

32 The two redlines in the graph represent the degree of uncertainty surrounding the impulse function.
33 Among which the insignificance of LME prices for Chinese producers, on the contrary, to SHFE prices, or missing variables such as exchange and interest rates.
IV. Conclusion

As a very energy-intensive sector, the aluminium industry has a substantial impact on GHG emissions (mainly CO₂ and PFC), not only directly from the process of reducing alumina into liquid aluminium, but also indirectly from the entire production process starting with bauxite mining up to ingot casting. We cannot however deny that tremendous efforts have been engaged to diminish global emissions on a relative basis. China, by far the world’s largest producer of primary aluminium, has in particular heavily invested to set up new production capacities with a lower energy intensive electrolysis process resulting in a less-than-proportional increase in GHG emissions.

In spite of this positive trend and concerning the global warming effects of the aluminium industry, there are, however, as many reasons to rejoice as there are causes for concern. First, as always when it comes to GHG inventory data, figures should be interpreted with caution, especially in the case of coal firing, where the degree of uncertainty is at its highest. From this perspective, any “on average” reasoning could be seriously misleading. Second, despite the undeniable pledge from Chinese officials to implement better environmental practices and greater hydropower capacity, it should be noticed that the power mix used by Chinese smelters, where the weight of coal is quite overwhelming, has not evolved over the last decade. Finally, it does seem important to extend the appraisal of the GHG-Aluminium nexus beyond the over-convenient “per tonne of aluminium” framework and to question the propriety of soaring Chinese production capacities. In this respect, it would seem that Chinese producers are playing their trump card – one originating from the past distortion of electricity prices and R&D incentives – in a non-cooperative game to gain market shares in a context of plummeting prices. Therefore, the real question is about China’s competitive advantage in aluminium production when its energy and environmental problems are taken into account. To put it bluntly, the increase of Chinese aluminium production (+18% during the first half of 2015) is an economic non-sense and an ecological hold-up.
V. References

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V.I Appendix

Graph 10: Top 10 countries in the aluminium industry (million tonnes, 2013)

Graph 11: Top smelters in the world (T, 2013)
A LUMINUM AND GHG EMISSIONS: ARE ALL TOP PRODUCERS PLAYING THE SAME GAME?

Graph 12: Chinese Trade flows of unwrought aluminium (kT)

Graph 13: Chinese export structure of unwrought aluminium and semi-finished products (2012-2014, kT)

- Unwrought aluminium
- Aluminium powders and flakes
- Aluminium bars, rods and profiles
- Aluminium wire
- Aluminium plates, sheets and strip, thickness > 0.2 m
- Aluminium tubes and pipes