ST07 - Aluminium from the Amazon: Strengths, Weaknesses, Opportunities and Threats

Simon Lobach
Lecturer, Geneva Graduate Institute, Geneva, Switzerland
Corresponding author: simon.lobach@graduateinstitute.ch

Abstract

The Amazon region in South America historically comprises three aluminium-producing countries: Brazil, Venezuela, and Suriname, while Guyana is also home to several bauxite mines. In the Brazilian Amazon, we find two of the world's main aluminium producers: Alcoa and Norsk Hydro. These companies are among the avant-garde in terms of sustainability, as certified by the Aluminium Stewardship Initiative (ASI). They have earned their reputation as sustainable producers thanks to cutting-edge technologies applied in mining as well as in alumina and aluminium production. Examples include the management of bauxite tailings, measures for safer disposal of bauxite residue (colloquially called red mud), the greening of the energy mix used, decarbonization of the smelting process, and reforestation programmes at the impacted sites. The fate of Venezuela and Suriname is a different one: after successful operation for decades, the aluminium smelters in these countries have shut down their operations, due to diverse factors, leaving the facilities in ruin and forming a considerable threat to the environment and to social wellbeing. A comeback will be difficult if it will happen at all.

Bringing a social science perspective, Simon Lobach has studied the environmental performance of aluminium producers in the Amazon. Besides the actions of aluminium producers, he has also taken the fragility and global importance of this unique ecological biome into account. Based on a several-year research project on aluminium production in the Amazon, he presents his findings in the form of lessons for sustainability from the aluminium producers in the region, but also insights that the sector can obtain from a wide array of academic and societal actors in the region that were consulted in the context of this project regarding responsible operations in this highly diverse, rich, yet vulnerable biome.

Keywords: Aluminium in the Amazon, Sustainability, Environmental performance, Bauxite residue.

1. Introduction

The Amazon region in South America extends over nine different countries. It contains vast bauxite deposits, which have been exploited since 1915, when the Aluminum Company of America (Alcoa) acquired its first concessions in two territories in the northern Amazon that were then under colonial administration: British Guiana and Dutch Suriname. At that time, the First World War made it necessary to build fighter aircrafts, for which aluminium was required. Aluminium played an even larger role during the Second World War. During that conflict, Suriname was the largest bauxite exporter worldwide, helping the Allied Forces to victory. After the war, Suriname attempted to capitalize on this position by setting up its own aluminium smelter within the country. For this, it needed an alumina refinery, but also a reliable source of electricity, for which a hydroelectric dam was built. Alcoa created the necessary infrastructure in Suriname, so that the first Amazonian aluminium was produced here in the late 1960s. British Guiana has attempted to follow this example since that time, and has continued doing so after it became the independent country Guyana, but these efforts have had ups and downs with some indications of a potential revival today [1, 2].

The aluminium sector in the Amazon expanded especially when Brazil and Venezuela joined the game in the 1970s and 80s. In Brazil arose the aluminium smelters Albrás in Barcarena (formerly operated by Vale, now by Hydro) and Alumar in São Luís do Maranhão (operated by Alcoa). Venezuela built two smelters (Alcasa and Venalum) in Ciudad Guayana, both operated by the state company Corporación Venezolana de Guayana – CVG.

For this to happen, both Brazil and Venezuela also built hydroelectric dams to power the smelters. Even today, some of these dams are among the largest worldwide: the Guri Dam in Venezuela and the Tucuruí Dam in Brazil.

The two Brazilian smelters have a considerable output. Albrás produces around 460 000 tonnes per year [3]. Alumar was deactivated for several years because of high electricity prices, but reopened in 2022 and is aiming to fulfil its potential of 447 000 tonnes again very soon [4]. These two Brazilian smelters rely on bauxite from mines in Trombetas, operated by the Brazilian stock company Mineração Rio do Norte (MRN); Paragominas, operated by Hydro; and Juruti, operated by Alcoa. Two alumina refineries exist in the Brazilian Amazon, both built next to the smelters that they supply to. The alumina refinery in Barcarena (Alunorte) has for a long time been the largest in the world. Figure 1 shows the location of the facilities used for aluminium production in the Amazon.

Figure 1. The northeastern Amazon, with the different components of the aluminium supply chain. The orange symbols indicate bauxite mines, grey symbols alumina–aluminium production facilities, and the blue symbols major hydroelectric plants. The black lines indicate the main electricity transmission lines connecting the hydroelectric plants to the aluminium plants, while the red line shows the slurry pipeline transporting liquefied bauxite from Paragominas to the alumina plant in Barcarena. Source: Own elaboration using Google Maps.

The other three smelters in the Amazon are in a much less favourable situation. The aluminium smelter in Paranam, Suriname, is permanently closed. It was a victim of the disadvantage of being a pioneer. As of the 1970s, the aluminium sector worldwide went through a time of significant scale-up and technological innovation. The smelter in Suriname was relatively modest in size, and the technology was soon outdated. This caused operation costs to be too high for Surinamese aluminium to be profitable, but the inefficiency of the hydroelectric power plant in Brokopondo also played a large role herein. Moreover, Suriname in the 1980s was the stage of severe civil strife between an authoritarian government and ethnic groups from the country's interior, who had been to a large extent removed from their homes for the sake of bauxite concessions and the Brokopondo hydroelectric reservoir [5]. As part of this conflict, attacks were launched on the bauxite mining town of Moengo, while the power lines linking the Brokopondo Dam to the aluminium smelter in Paranam were blown up [6]. Alcoa attempted to resume aluminium production but eventually left the country. Today, Suriname does not even export bauxite anymore.

The two aluminium smelters in Venezuela, Alcasa and Venalum, are also closed, as a result of the deep political, economic, and environmental crisis the country is traversing. The immediate cause has been the power cuts that have plagued the smelters over the past few years, shutting down the last remaining electrolysis cells, on 8 March 2019, after gradual decline of production during the previous 10 years [7, 8]. However, the overarching company CVG does not publicly admit this, and information from the Venezuelan aluminium sector can only be obtained indirectly.

In the context of a several-year research project, I have looked at the past and present of aluminium production in the Amazon, and assessed it, not only from the perspective of the industry, but also from the perspective of this very fragile and ecologically essential biome. To provide insights into the environmental performance of aluminium production in the Amazon, I perform a SWOT analysis, citing three strengths, three weaknesses, three opportunities and three threats for the industry. This SWOT analysis concerns the full supply chain of primary aluminium, including bauxite mining, alumina production and hydropower generation, besides aluminium smelting.

While my wider research also takes the stories of failed aluminium production in the Amazon into account (regarding Guyana, Suriname and Venezuela), the SWOT analysis below is primarily concerned with the two smelters that are still active today, meaning the two located in Brazil. However, lessons learned from the other smelters are sometimes referred to, as they can be valuable for the active smelters as well.

The issue at hand is highly complex, and this paper rather short. As a result, no justice could be done to all the different relevant aspects, for which I gladly refer to my upcoming PhD dissertation.

2. Strengths

2.1 Source of Energy

While aluminium has historically been mostly produced with hydroelectric energy, this has started to change since the 1990s. According to data of the International Aluminium Institute (IAI), in 2021 over 66.6 % of the aluminium produced worldwide comes from smelters that are powered with fossil fuels (56.9 % coal and 9.7 % gas). This is a relatively new phenomenon: until 2000 hydroelectricity was the largest source of electricity for aluminium smelting worldwide (see Figure 2). This change in sources of electricity accompanied a rearrangement of the countries where most of the aluminium smelting capacity was located, with aluminium production shifting to China and India, where it is based predominantly on coal, and to the Middle East, where it is powered with natural gas (see Figure 3).

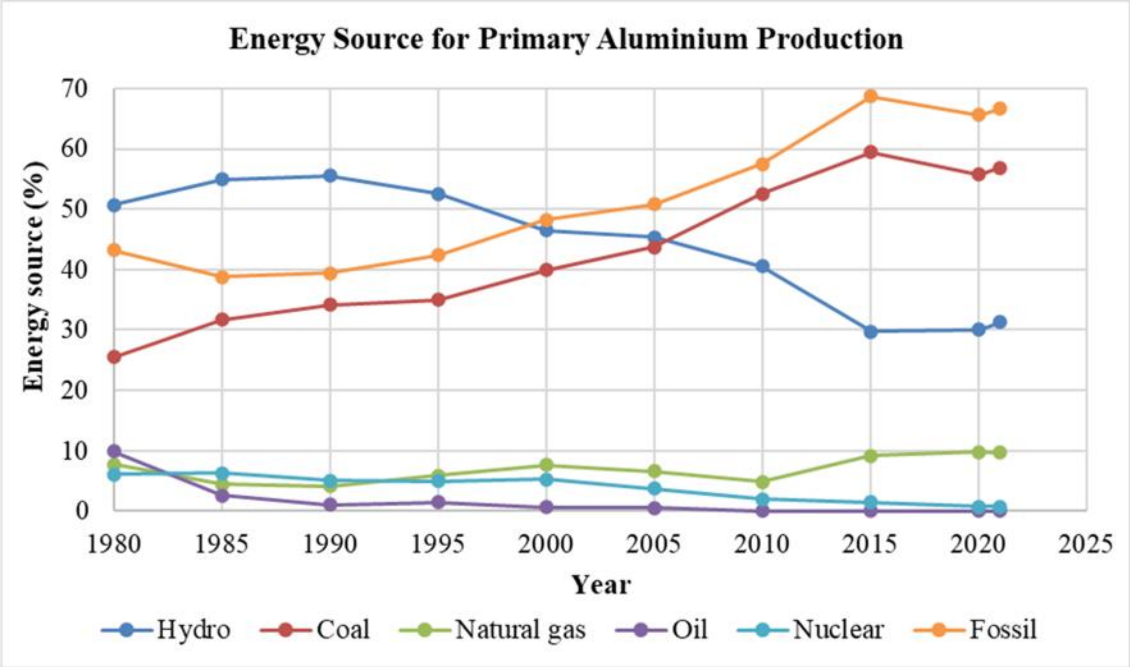

Figure 2. Source of energy in primary aluminium production, from 1980-2021. Source: IAI data [9].

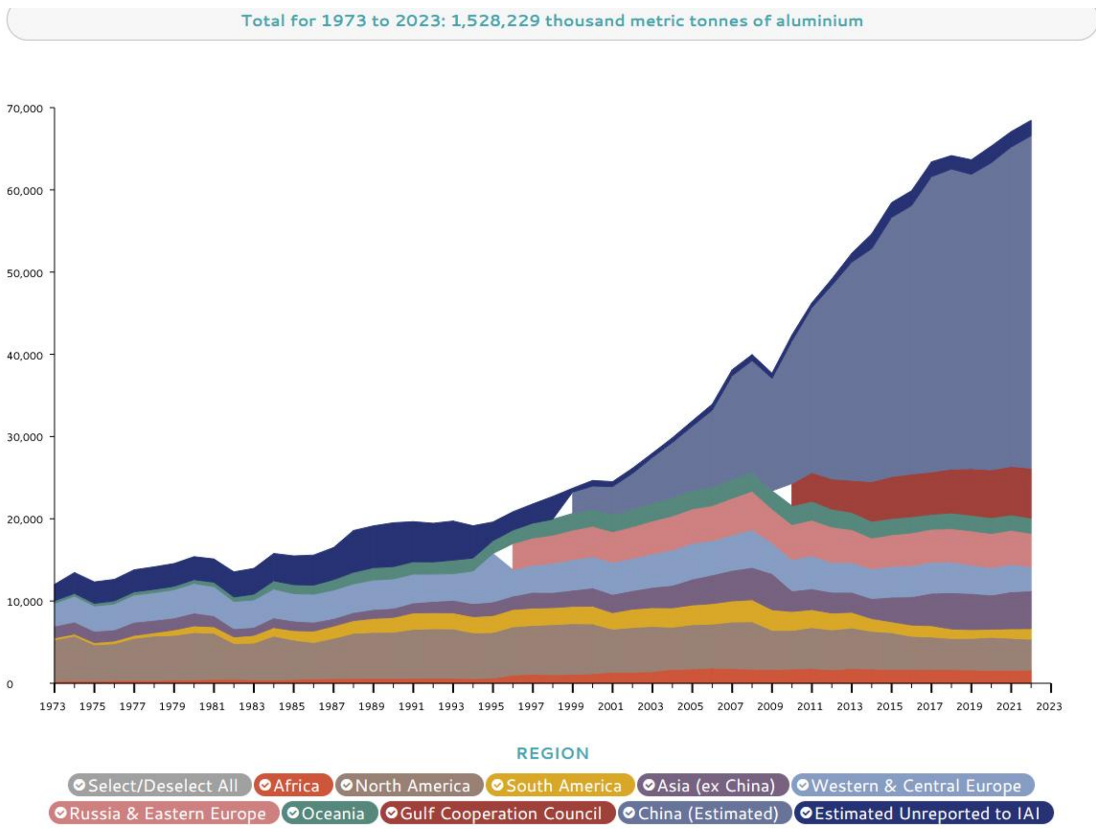

Figure 3. Aluminium output per country, per year (1973-2022) [9].

At the same time, in the Amazon, a region with an enormous endowment of water resources, aluminium continues being produced with the help of hydroelectricity. Seen in that light, aluminium production in the Amazon represents a relatively "green" portion of the international aluminium market. Indeed, an analysis of greenhouse gas emissions per tonne of aluminium produced showed that countries like Brazil, Suriname and Venezuela in 2012 had the capacity (based on their energy mix) to produce aluminium with lower CO_2-equivalent emissions than most other countries [10]. Certain other producers have brought down the CO_2 intensity of their aluminium industries since then [11], but still, Amazonian producers, with their smelters powered exclusively with hydroelectricity, are among the ones that have the lowest CO_2 emissions per tonne of aluminium produced, along with countries like Iceland, Norway and Canada, which also use exclusively renewable sources of electricity.

2.2 Technological Innovation

Most of the companies that are still active in the Amazon (namely, Norsk Hydro, Alcoa and Mineração Rio do Norte (MRN)) are among the frontrunners in reducing the environmental footprint of aluminium production. This can be concluded from the fact that Alcoa and Hydro are part of the worldwide effort to cut out direct CO_2 emissions from aluminium smelting. The ELYSIS and HalZero technologies that Alcoa, Rio Tinto and Norsk Hydro have recently presented aim to do exactly that: to redesign the chemical process for aluminium production so that it does no longer emit CO_2. Furthermore, the reforestation projects that MRN, Hydro and Alcoa have implemented at their production sites are a factor that reduce the long-term deforestation linked to aluminium production, and hence limit the CO_2 emissions associated to the operations.

Figure 4. Reforestation programme of the bauxite mining company Mineração Rio do Norte (MRN) in Trombetas, Brazil. The company runs a tree nursery (left), where up to a million tree seedlings per year are grown from seeds collected in cooperation with local communities. These seedlings are subsequently replanted at the former bauxite mining sites. The oldest secondary forests planted by MRN are already over 30 years old. These are thick forests full of wildlife. Other bauxite mines in Brazil, such as the ones operated by Alcoa and Hydro, also have reforestation programmes, but MRN is by far the oldest and largest reforestation initiative implemented by a bauxite mining operation. Photos: author, 2023.

Another new technology has been implemented by Hydro in Paragominas: the dry tailing management (Figure 5) [12], which reduces the risks of dam breaks, which can lead to disasters if tailings flood local communities and ecosystems. This is especially relevant since Brazil has recently seen such disasters, linked to iron ore mines in Brumadinho and Mariana. Also, the bauxite sector has caused such damage: in the late 1980s; bauxite tailings were deposited in the nearby lake Lago da Batata by MRN. This led to national outrage, representing the turning point for the company to make its practices more sustainable.

Figure 5. The new tailings management method developed by Norks Hydro at its bauxite mine in Paragominas (Brazil). The method, called Tailings Dry Backfill, allows for water removal from bauxite tailings through drainage and evaporation. This technology makes the use of dams to contain bauxite tailings unnecessary. Tailing deposition is a contentious topic in Brazil as accidents with such dams in Brazilian iron ore mines have in the recent past made many victims and caused significant environmental damage. Photo: member of Norsk Hydro's communications team, during visit of the author, 2022.

Moreover, Hydro has built a bauxite slurry pipeline, the first of its kind, running from Paragominas to Barcarena. This pipeline transports liquefied bauxite from the mine to the alumina refinery, replacing the trucks that would have otherwise been required. Besides causing CO_2 emissions, truck transportation in the Amazon often leads to other social problems, as the roads traverse local communities, exposing the inhabitants to accidents, air pollution and social problems involving truck drivers. Replacing truck traffic with a pipeline thus constitutes an improvement of local populations' safety. It has to be admitted, on the other hand, that the communities that live in the areas that the pipeline traverses are also citing adverse effects, especially linked to the works surrounding the replacement of the pipelines and the fear of leaks into rivers and streams.

The measures mentioned above (reforestation, improved tailing management, other ways of bauxite transportation) show that the three companies that are active in the Brazilian Amazon are making several attempts to reduce the socio-environmental impacts of aluminium production. If other players on the international aluminium market, the vast majority of which have less sustainable production practices, would enter the Amazon, the impacts are very likely to be much more severe.

2.3 Community Relationships

The arrival of an industry always impacts local societies and environments. Aluminium is a particular point in case, due to the triple impact of bauxite mining sites, hydroelectric power plants and reservoirs, and the industrial facilities with associated bauxite residue basins. Aluminium companies in the area thus have an important responsibility to maintain good relationships with local communities, and to make sure that these can share in the benefits of aluminium production. While this was certainly not the case for the earlier aluminium projects in the Amazon [13-15], the companies (currently) active in the Amazon have increasingly invested themselves in improving community relationships, through different social and environmental projects at the locations where they are active.

3. Weaknesses

3.1 Local Communities' Land Property Rights Have Historically not been Respected

This relationship with affected communities is also a weakness. Since the beginning of bauxite mining in the Amazon, aluminium companies, as well as their partners in the public sector, have ignored property rights of traditional populations. This was possible because property rights in the Amazon function in different, more informal ways than in the companies' countries of origin. It is often assumed that the processes we have come to describe as "development" or "progress" are automatically inclusive. In the Amazon, we witness the opposite. Yes, industrial development creates jobs, but not for the traditional Amazonian populations. And all too often, local populations lose the lands and resources that they relied upon for their livelihoods, without receiving proper compensation.

Moreover, State representatives were often eager to facilitate the settlement of an aluminium industry in their countries, in order to maximize their tax revenue. As the local communities hardly contributed to the States' tax income, the State often deliberately and structurally downplayed estimates of the amount of people that would need to be displaced for the projects linked to the aluminium sector. Moreover, even before the arrival of the industry, "landlords" had often secured formal ownership of enormous tracts of land through the scams that are known in Brazil as "*grilagem*" (land-grabbing). Traditional communities were often unaware of these changes of ownership, which often only existed on paper, until the bulldozers arrived to remove them from their lands [16].

The aluminium sector has been present in the Amazon for little over a century. In those years, tens of thousands of people have been displaced from their ancestral lands, where they farmed, fished and lived, in order to make way for bauxite mines, industrial facilities, harbours, and reservoirs for hydroelectric plants [17-19]. Many of these people are still living close to the production facilities, and many of them claim compensation for what they have lost. Given the low productivity of Amazonian soils, when a community is resettled to another location but not provided with an adequate territory to farm, fish, and collect food items and other forest products, this community will not be able to survive as it used to. In some cases, they have seen themselves forced to move into other, more polluting activities, such as gold mining [19].

3.2 Aluminium and Other Sectors Reinforce Each Other's Impacts

Aluminium was one of the 'first movers' into the Amazonian space, meaning that the industry-built roads and power lines into areas where none of these existed before. While presented as vehicles for progress and development, such roads and power lines also opened forest areas to other sectors, like logging, cattle farming, gold mining, etc. Especially around the hydroelectric plants that were built exclusively to power aluminium plants, large-scale environmental destruction can be observed, caused by other actors that were inadvertently given access to these areas (see Figure 3). Furthermore, industrial towns like Barcarena (Brazil) and Ciudad Guayana (Venezuela) attract other polluting industries as well, which set up shop next to the aluminium smelters, creating pollution clusters in the Amazon. An example could be the kaolin industry in Barcarena, which also makes use of basins to deposit toxic rest materials.

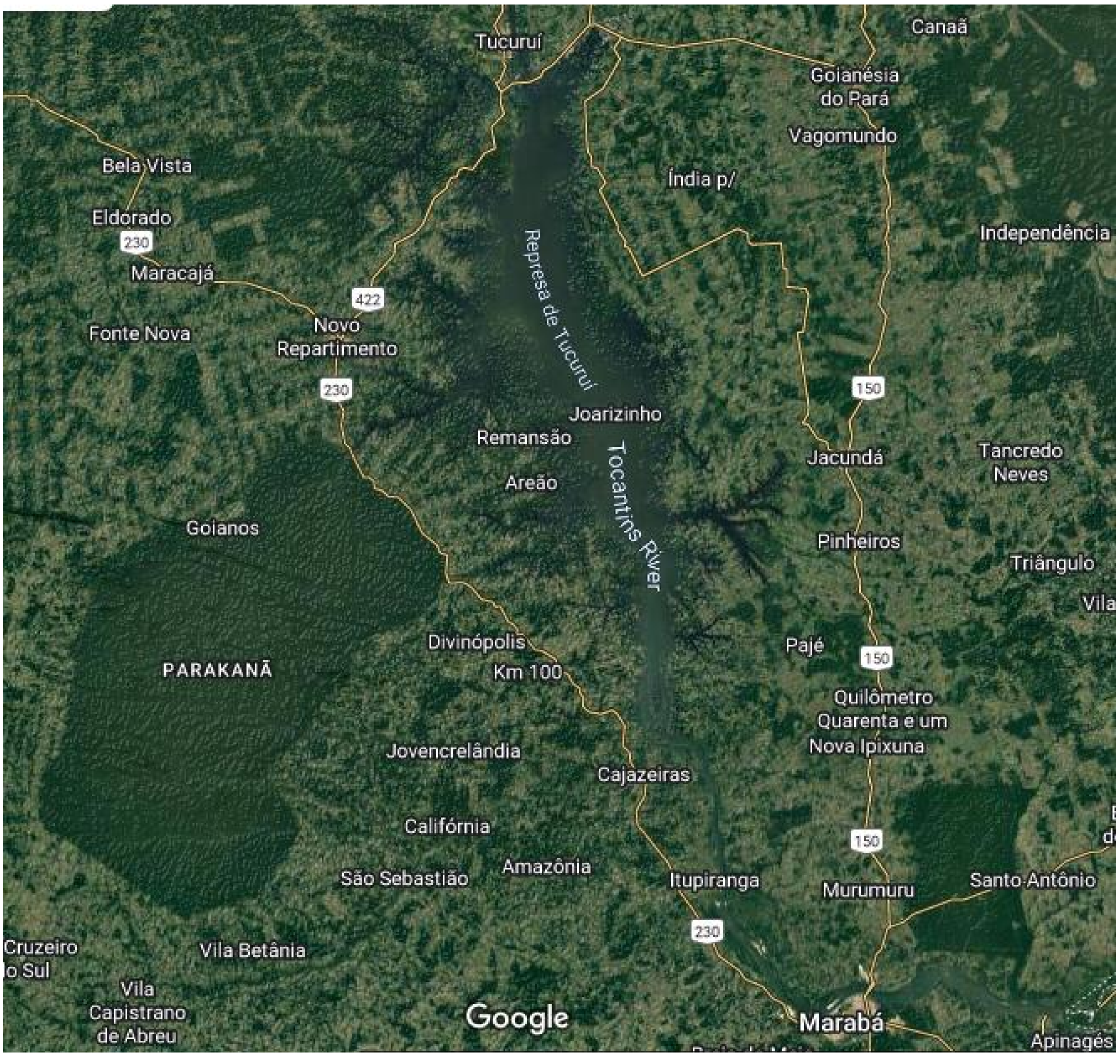

Figure 6. The hydroelectric plant at Tucuruí was built specifically to power the aluminium smelter in Barcarena. When construction started, it was in the middle of the forest. Currently, the entire area around the reservoir (the "Represa de Tucuruí" on the map) has been deforested (see the light green colour), with the exception of two Indigenous reserves, the dark green areas of the Parakanã community (lower left corner) and the area called "Mãe Maria" close to Santo Antônio in the lower right corner of the map. Source: Google Maps, 2022.

3.3 Inefficiency of Hydroelectricity Generated in the Amazon

As the Amazon is a rather flat region, the hydropower plants in this region are very inefficient in terms of the amount of territory flooded for each additional unit of electricity. In the Amazon, we can find large reservoirs that produce small amounts of energy when compared to reservoirs in more mountainous regions of the world. For example, the Guri Dam in Venezuela floods 0.415 km^2 of land for each MW of installed capacity, and the Tucuruí Dam in Brazil floods

0.360 km^2 for each MW. By contrast, the Three Gorges Dam in China, for example, floods only 0.048 km^2 per MW produced, and this figure is almost 0.000 km^2 for the last generation of flow-of-the-river dams [20].

Furthermore, the lands that are flooded by reservoirs in the Amazon were all forested before, and as such they used to function as carbon sinks. Since the forest cover was not removed when the dams were constructed (see Figure 7), these rotting forests continue emitting methane [21] [22], which is a much more powerful greenhouse gas than CO_2. As a result, one could put some question marks at claims of hydropower in the Amazon being a 'green' energy source.

Figure 7. These trees in the Brokopondo dam reservoir (Suriname) died over 50 years ago, when a hydroelectric plant was built here to power the Paranam aluminium smelter. On top of losing its capacity to serve as a carbon sink, the drowned forest may still be emitting methane. In the meantime, the Paranam aluminium smelter – the reason why these trees were drowned in the first place – has already been switched off. Photo: Ted Sun, 2020.

4. Opportunities

4.1 Aluminium Companies Could Contribute to Better Environmental Management in the Amazon

Opportunities abound in the Amazon for companies willing to genuinely improve local environments and living conditions, but they need to adopt a more holistic view to make a positive impact. Amazonian populations are strong and resilient, and their environment provides them with many livelihoods. Their problem is not poverty, but threats to their lands and environmental assets. Insufficient levels of governance, weak institutions and inadequate monitoring play a crucial role herein.

Companies that extract riches from the Amazon and wish to return something to the region should not focus on community projects only, but also help improve institutional governance. This would enable Amazonians to look after their own interests, so they will not need to depend on charity work any longer. In order to achieve this, aluminium companies in the Amazon should cooperate much more closely with environmental agencies within governments, and be open to learn from social scientists and research institutions in the region as well as abroad.

4.2 The Aluminium Sector Could Contribute to Creating Employment in the Amazon

The arrival of foreign companies in the Amazon is normally defended with reference to the supposed 'progress' and 'development' they would bring. Many Amazonians hope to be employed by these companies.

The aluminium industry has not yet fulfilled this promise of creating employment for the local population. A major problem of the aluminium industry is that it is energy-intensive, not labour-intensive, while the Amazon is a region that is poor in energy resources and rich in labour, as a result of the number of people who for diverse reasons have been displaced from their lands [18].

For this reason, the aluminium industry could make a difference by not only producing aluminium ingots in the Amazon, but also erecting industries for aluminium-based consumer products in the cities in the Amazon region. In doing so, a leading principle should be to maximize the number of jobs created whilst limiting environmental impacts. The necessary training should also be provided to ensure that, rather than attracting more in-migration from other regions of Brazil, an Amazonian workforce can take up these opportunities.

4.3 Aluminium Companies Should Invest in Secondary Aluminium

Another opportunity is linked to the huge waste problem in the Amazon, caused by failing waste collection services. The very substantial rainfall and the fluctuating water levels cause garbage to make its way into ecosystems very quickly. Aluminium, in the form of beverage cans for example, is an important contributor to garbage in the region. Recycling systems at the consumer level are mostly absent. Informal workers go through the garbage to recover aluminium. The people performing such work are often of very low social standing, many of them homeless. The aluminium beverage cans, if they are collected at all by these informal workers, are then shipped to far-away recycling plants.

Aluminium companies could take up an important responsibility dealing with aluminium and other waste in Amazonian cities, setting up proper waste collection services and investing in aluminium recycling. In the process, they could contribute to formalizing the jobs of garbage recyclers, and improve the awareness of Brazilian consumers regarding the value of aluminium, the ecological cost of its production, and the need to dispose of it responsibly, so that it can be recycled.

5. Threats

5.1 Threat of Bauxite Residue Overflowing

A major threat caused by aluminium production is 'bauxite residue' deposition by alumina refineries. Over the past twenty years, several accidents have occurred with bauxite residue leaking into streams and rivers, with a major incident occurring in 2018. In that year, a Hydro bauxite residue reservoir overflew, causing substantial environment and community damage [23], and forced the company to operate Alunorte refinery at half capacity until May 2019. However, according to the company itself, the bauxite residue never leaked into the surrounding environment [24], and court hearings over the case are still in progress.

Water pollution and loss of soil fertility due to incidents involving bauxite residue have direly affected local communities. While the security of bauxite residue deposits has improved significantly over the past few years, it needs continued close monitoring to prevent it from threatening local populations again. The Amazonian torrential rains, exacerbated even more by climate change, amplify the risks of basins overflowing.

5.2 Bauxite Residue Needs Permanent Monitoring

The monitoring of dangerous substances, like bauxite residue, often stops after an industry has left a country. This may not be on anyone's mind in Brazil today, but sooner or later alumina production will end, and it may become unclear who should be responsible for the management of these toxic basins after that, especially if the State lacks the capacity to take this responsibility. The cases of Suriname and Venezuela have taught us that such a moment may arrive sooner than anyone expects. In Venezuela, I interviewed a retired environmental engineer, formerly responsible for the security of bauxite residue basins in that country. He informed me that after the closure of the factories, monitoring was discontinued.

5.3 The Aluminium Industry Must Win the Hearts of Amazonian Populations

Finally, the very difficult historical relation between aluminium industry and traditional populations constitutes a major threat. This forms a risk for the industry in terms of reputation, as affected communities have become increasingly vocal and now bring their concerns to local and international audiences. But it is also a physical risk, as the Surinamese case shows, where the power lines linking the hydroelectric dam to the aluminium smelter were blown up by the so-called "Jungle Commando", which claimed to represent the ethnic groups that had lost their lands for bauxite concessions and the Brokopondo reservoir [25]. Repairing this relationship is an absolute necessity to end the tension around aluminium production in the Amazon.

6. Conclusion

Overall, the aluminium industry in the Amazon is moving towards increasingly sustainable practices. However, challenges remain, including the need for stronger community relations, mitigation of unintended environmental consequences, and responsible waste management. By seizing opportunities to enhance the region's well-being and livelihoods, the industry can contribute to sustainable development in the Amazon, and truly fulfill its promise of being a producer of "green" aluminium.

7. Acknowledgement

Elements of this research were funded by the European Research Council (grant 950672).

8. References

1. Sylvester Carmichael, *The rise and fall of Guyana bauxite*, Master of Science Thesis, Colorado School of Mines 2002, Published by ProQuest LLC 2018, https://repository.mines.edu/bitstream/handle/11124/15628/Carmichael_10794659.pdf?sequence=1 (accessed on 15 August 2023).
2. Chinese company invests US$115M to improve bauxite production in Guyana, Guyana Times, 8 July 2023, https://guyanatimesgy.com/chinese-company-invests-us115m-to-improve-bauxite-production-in-guyana/ (accessed on 15 August 2023).
3. Norsk Hydro's website: www.hydro.com/en-BR/about-hydro/hydro-worldwide/americas/brazil/barcarena/albras/?gclid=Cj0KCQjwkqSlBhDaARIsAFJANkjC-c7DVpY_mo8p8iJJBeIXzm0TKafl2_NY_VryA_LiCjv-A14IGvcaAmAiEALw_wcB .
4. Alumar Fact Sheet that can be found on Alcoa's website: www.alcoa.com/brasil/pt/pdf/brasil-alumar-fact-sheet.pdf.
5. Simon Lobach, Aluminium in Suriname (1898–2020): An industry came and went, but its impacts on the Maroon communities remain, *International Development Policy*, Vol. 16, (2023), https://doi.org/10.4000/poldev.5331.

6. For details on this Civil War, called the War of the Interior (1986–1992), please see: Wim Hoogbergen and Dirk Kruijt, *De oorlog van de sergeanten: Surinaamse militairen in de politiek.* Amsterdam, Uitgeverij Bert Bakker, 2005, 308 pages.
7. H. Medina, The rise and fall of CVG Venalum primary aluminium plant, *Light Metals* 2021, 401-405.
8. Venezuela blackout dooms aluminium industry: Will SA suffer the same fate?, *Aluminium Trading* 20 March 2019, www.aluminiumtrading.co.za/2019/03/20/venezuela-blackout-dooms-aluminium-industry-will-sa-suffer-the-same-fate/ (accessed on 15 August 2023).
9. Source: database of the International Aluminium Institute, London. https://international-aluminium.org/statistics/primary-aluminium-smelting-power-consumption/ (Accessed 5 June 2023).
10. D. Paraskevas, K. Kellens, A. van de Voorde, W. Dewulf and J.R. Duflou, Environmental impact analysis of primary aluminium production at country level, *Procedia CIRP* 2016, Vol. 40, Fig. 2.
11. Ali Hasanbeigi, Cleanest and dirtiest countries for primary aluminum production. Global Efficiency Intelligence website, 29 March 2022, www.globalefficiencyintel.com/new-blog/2022/cleanest-and-dirtiest-countries-for-primary-aluminum-production.
12. Hydro, Novel bauxite tailings concept a success in full operation, Hydro website, 25 October 2021. www.hydro.com/en/about-hydro/stories-by-hydro/novel-bauxite-tailings-concept-a-success-in-full-operation/.
13. See, for example, my article on the socio-environmental impacts of the aluminium industry in Suriname (Lobach, 2023, *op.cit.*) [5].
14. For the Brazilian case, see Marcel Hazeu and Solange Gayoso da Costa, *Amazônia em Guerra: (Re)existência e Disputa Territorial em Barcarena.* Belém, Editora Paka-Tatu, 2022, 140 pages.
15. G.M. Biery-Hamilton, The differential impacts of development upon an urban population on the Tucuruí reservoir, Pará, Brazil. S. Barbosa Magalhães, R. de Caldas Britto and E. Ramos de Castro (org.), *Energias na Amazônia*. Belém, Museu Paraense Emílio Goeldi, Universidade Federal do Pará and Associação de Universidades Amazônicas, 1996, 361-392.
16. An example of this process can be found in Oscar de la Torre, *The People of the River: Nature and Identity in Black Amazonia, 1835-1945.* Chapel Hill, The University of North Carolina Press, 2018, 242 pages.
17. Marcel Theodoor Hazeu, *O não-lugar do outro: Sistemas migratórios e transformações sociais em Barcarena.* Belém, Universidade Federal do Pará, 2015, 335 pages.
18. Sônia M. Simões Barbosa Magalhães Santos, *Lamento e dor: Uma análise sócio-antropológica do deslocamento compulsório provacado pela construção de barragens.* Belém and Paris, Universidade Federal do Pará and Université Paris 13, 2007, 278 pages.
19. Lobach, 2023, *op.cit.,* [5].
20. All calculations performed by the author on the basis of information made available by the companies operating the relevant dam.
21. Philip M. Fearnside and Salvador Pueyo, Greenhouse-gas emissions from tropical dams, *Nature Climate Change*, Vol. 2, (2012).
22. Philip M. Fearnside, Environmental and social impacts of hydroelectric dams in Brazilian Amazonia: Implications for the aluminum industry, *World Development*, Vol. 77, (2016).
23. Edna Castro and Eunápio Dutra do Carmo (org.), *Dossiê Desastres e Crimes da Mineração em Barcarena, Mariana e Brumadinho,* Belém, NAEA Editora, 2019, 256 pages.
24. Hydro, *Timeline and overview of the Alunorte situation.* 26 September 2019. www.hydro.com/globalassets/07-media/brasil-situation/documents/alunorte-timeline.pdf (Accessed 9 September 2023).
25. Hoogbergen and Kruijt, 2005, *op.cit.*, [6].