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Environmental and Social Impacts of Hydroelectric Dams in Brazilian Amazonia: Implications for the Aluminum Industry

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ABSTRACT

Aluminum smelting consumes large amounts of electricity and helps drive dam-building worldwide. Brazil plans to build dozens of hydroelectric dams in its Amazon region and in neighboring countries. Benefits are much less than is portrayed, partly because electricity is exported in electro-intensive products such as aluminum, creating little employment in Brazil. Dams perversely affect politics and social policies. Aluminum export offers an example of how a rethinking of energy use needs to be the starting point for revising energy policy. Dam impacts have been systematically underestimated, including population displacement and loss of livelihood (especially fisheries), biodiversity loss and greenhouse-gas emissions.

Keywords:

Aluminum industry; Amazonia; Energy policy; Global warming; Hydroelectric dams; Brazil

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Introduction

Dams have been built on most of the major rivers in industrialized countries, and the combination of decreasing availability of sites with hydroelectric potential in North America and Europe and decreasing tolerance of the public in these areas to accept major impacts has led to a shift of dam building to developing countries (Khagram, 2004). As of 2014 there were 37,641 dams in the world with ≥ 15 m height; of the 36,259 of these that had data on use, 8689 were either wholly or partially for hydropower (ICOLD, 2014). In addition to a surge in dam-building activity in China and in the Himalayan region, construction is increasing and future plans are massive in tropical areas in Latin America, Africa and Southeast Asia (e.g., Richter et al., 2010; Tollefson, 2011). Aluminum smelting, an activity that consumes large amounts of electricity, has also progressively moved to these locations, including Brazil (do Rio, 1996). The environmental and social consequences are great wherever large dams are built. Iconic examples include the Narmada Dams in India (Morse et al., 1992; Fisher, 1995), the Three Gorges Dam in China (Dai Qing, 1994; Fearnside, 1988, 1994) and the planned Mekong River Dams in Southeast Asia (Baran et al., 2012; Grumbine & Xu, 2011). Ignoring or underreporting of large impacts in decision making is by no means restricted to developing countries, as shown by the history of dam building in the United States (Morgan, 1971). Dams have benefits as well as impacts, but it is the large impacts that make consideration of how electricity is used such a vital (and often neglected) aspect of planning and decision making in tropical countries.

Decisions on dam building are not only influenced by the balance (or lack thereof) in reports such as environmental impact studies (EIAs), but also by political processes, including the action of non-governmental organizations ranging from grassroots associations of affected people to international environmental and human-rights organizations. Khagram (2004) reviews the roles of these actors in dam decisions in various developing countries, showing the differences between countries with high degrees of both democracy and social mobilization (India and Brazil), with democracy but low mobilization (South Africa and Lesotho), little democracy but high mobilization (Indonesia), and low levels of both democracy and mobilization (China). The power of the massive financial and political interests surrounding dams, including transnational interests, is evident even where civil society is free and active.

Brazil has embarked on an unprecedented drive to build hydroelectric dams in the Amazon region (Figure 1). Brazil had 15 “large” dams (defined in Brazil as > 30 MW installed capacity) in the country’s Legal Amazon region with reservoirs filled by May 2015 (Table 1). An additional 37 “large” dams planned or under construction are listed in Table 2, including 13 as-yet unfilled dams that were included in Brazil’s 2012-2021 Energy Expansion Plan (Brazil, MME, 2012, pp. 77-78). Brazil’s economic retraction since that plan has resulted in lengthening time horizons for several of these projects, but the 2014-2023 plan still includes 18 Amazonian dams in its 10-year schedule (Brazil, MME, 2014, pp. 80-81). The 51 existing, under-construction and planned dams listed by number in Tables 1 and 2 are mapped in Figure 1. Many others have been inventoried (e.g., Brazil, ANA, nd [C. 2006], pp. 51-56), including 62 additional dams listed in Brazil's 2010 Plan (Brazil, ELETROBRÁS, 1987; see: Fearnside, 1995). In addition, Brazil plans to build six dams in Peru and one in Bolivia over this period, mainly for exporting electricity to Brazil (Finer & Jenkins, 2012; Wiziack, 2012).

[Tables_1_&_2_&_Fig_1_here]

The main argument used to promote hydropower as Brazil's preferred option for electricity production is that dams are (supposedly) the least-expensive option in terms of monetary investment per kWh of generation. However, this argument is open to question because dams almost always cost much more and take longer to build than originally assumed, making them considerably less attractive in financial terms than thought when the decision is made. This is a worldwide phenomenon, as shown by a recent global review of hundreds of unprofitable hydroelectric projects (Ansar et al., 2014). Most recently in Brazil, the Belo Monte Dam's cost is already double the government's initial estimate (e.g., *Veja*, 2013). In addition to the high cost of dams in terms of cash outlays, the non-monetary social and environmental costs of this option are tremendous and have little weight in critical decisions on energy options. Many of Brazil's planned dams are in Amazonia because the best sites in other regions of the country have already been dammed.

The present paper examines environmental and social costs and benefits of primary aluminum and reviews impacts of Amazonian dams. The paper is limited to addressing the relation between aluminum and Amazonian dams and their impacts; a reform of energy policy requires addressing many other issues needed to reduce energy consumption and to provide alternative sources of electricity. However, Brazil's energy policy can be broken down and addressed in more-manageable parts. A good place to begin is the question of aluminum export. Change is best achieved by focusing attention on one or a few factors (in this case aluminum) and identifying critical points that impede social and environmental objectives from being attained. This is an approach in the field of political ecology.

In a review of the political ecology of large dams, Nüsser (2003) finds that the aluminum industry is "intimately linked to the dambuilding lobby." Questions surrounding Brazil's Amazonian aluminum industry are central to other fields as well. Paul Ciccantell has applied both the social constructionist approach from environmental sociology (Ciccantell, 1999a) and new historical materialism (which combines methods of environmental sociology, sociology of development and social impact assessment) to interpret the role of these developments in globalization. He finds that "The incorporation of the Amazon via the aluminum industry is a key case of raw materials-based development in the era of globalization" (Ciccantell, 1999b, p. 177). Highly unequal distribution of impacts and benefits of Amazonian aluminum raises issues of environmental justice; concerns of this type have been shown to be important in bringing about change both at individual and societal levels (e.g., Reese & Jacob, 2015).

Aluminum and hydroelectric dams fit into the "resource curse" paradigm that is best known for mining but also applies to other forms of development where capital-intensive industries tap valuable natural resources. The seeming paradox of countries with the greatest mineral wealth having the highest incidences of poverty and the lowest indices of social wellbeing is a well-known and robust generalization; the greater the percentage of a country's gross domestic product that is derived from extracting minerals, the greater its poverty (e.g., Pegg, 2003; Sachs & Warner, 1995; Ross, 2001;

Rich, 2013; Weber-Fahr, 2002). Several factors contribute to the explanation of this phenomenon (Collier, 2007, pp. 38-52). One is the "Dutch disease," named after events in the 1960s when the advent of revenue from North Sea gas had the ironic result of worsening employment and general welfare in the Netherlands. This was because the natural-resource revenue caused the country's currency to strengthen, thereby rendering unprofitable the manufacturing and other employment-generating industries that had previously sustained the economy. Another factor is price volatility of extractive commodities, leading to effects that undermine governance and democratic institutions during both the boom and the bust phases of the cycles. Another factor leading to degradation of governance and consequent impacts on the poor is the tendency of resource extraction to generate wealth for large companies or wealthy individuals. This distribution affects the financing of central governments both through taxation and through more-direct contributions to political leaders through campaign donations and/or corruption. These leaders then become more responsive to the demands of their benefactors than to the interests of the population at large. Exploitation of hydropower fits this paradigm, although, in the case of Brazil, electricity exported as aluminum is only a part of a wider shift in the country's economy, with manufacturing being eclipsed by primary commodities like soybeans and iron ore. Dams are built by large companies, produce very little employment after the construction phase (especially if the power is used for aluminum), and the dam-building companies represent major donors to political leaders (as in the case of Brazil: see section on "The role of corruption").

The main purpose of this paper is to examine the environmental and social costs and benefits of primary aluminum production and review the impacts of Amazonian dams. The heavy environmental and social impacts of dams makes exporting electricity in the form of aluminum a poor development choice.

Costs and benefits of aluminum

Aluminum and dam building

In the 2011-2020 energy expansion plan the Brazilian government justified ambitious plans for Amazonian hydropower on the assumption that the country's gross domestic product (GDP) will grow at 5% per year over the period, as will demand for electricity (Brazil, MME, 2011, pp. 17 & 29). In deference to an undeniable economic slowdown, the 2012-2021 plan revised the annual rate to 4.4% for the 2012-2016 period, but maintained the 5% rate after that (Brazil, MME, 2012, p. 21). In any case, maintaining these rates would lead to astronomical assumed demand for electricity within a few years as a simple consequence of the mathematics of exponential growth. There is ample room to question both the realism of these assumptions (e.g., Costa, 2012) and the wisdom of important components of the assumed future growth, particularly export of energy-intensive commodities such as aluminum. The assumption is that government should race to produce electricity to supply whatever amount of power the market "demands" without questioning whether these uses are beneficial for Brazilian society. This demand is increasingly shaped by exports to global markets (Bermann, 2012a). In the case of primary aluminum, the key input is electricity rather than minerals or labor. In a panel discussion at the 4th International Aluminum Congress in São Paulo in 2010, the president of Alcoa Latin America and Caribbean stated that electricity represents 50% of total production costs in Barcarena and São Luis (Figure 2) (Highbeam Business, 2010). In 1989, electricity represented 35% of operating costs for smelting primary aluminum in Brazil, while labor represented 10% (US, DOE, 1997, p.

16). Expenditure on electricity and its proportion of the total cost depend heavily on the electricity rate charged, which varies in different locations and historical periods, but is invariably subsidized. Were the rate the same as that charged to residential consumers, for example, electricity would represent a much higher proportion of expenses. Rate contracts with aluminum companies have been tied to the international price of aluminum in much of the world, including Brazil (e.g., Brazil, MME, 1979). This creates a perverse situation where price determines cost, rather than the other way around (Burns, 2013). The result is the pattern of heavy subsidies and artificially low prices of both aluminum and electricity.

[Figure_2_here]

In 2004 a major price concession expired: the 20-year concession (1984-2004) made to Albrás (an enterprise then composed of 33 Japanese firms plus Companhia Vale do Rio Doce – a Brazilian government mining company, now named "Vale," that was privatized in 1997). The concession had set the price of electricity such that the cost of power consumed in smelting would not exceed 20% of the international price of aluminum (Brazil, MME, 1979), or only one-sixth of what residential consumers paid and one-third to one-half the cost of generating the power (Fearnside, 1999). Expiration of the concession was an opportunity for Brazil to either rid itself of this drain on its energy resources or to charge a price that would recover the full cost plus a reasonable profit. Instead, another 20-year concession was granted at subsidized rates that factory owners were confident would assure continued high profitability (Vale, 2004).

Aluminum ingots represent electricity in a form that can be loaded on a ship and taken away. Many other parts of the world would rather import the ingots than produce them at home because generating the large amounts of electricity needed to smelt aluminum has major social and environmental impacts (Müller-Plantenberg, 2006; Switkes, 2005). The smelting itself also has multiple impacts, such as a variety of occupational cancers and other diseases (Norseth, 1995). Social impacts can be substantial, as in the case of the Albrás smelters in Barcarena, Pará (Coelho et al., 2004; Monteiro & Monteiro, 2007). Essentially, the countries that import aluminum ingots or products (including partially transformed products such as rods and sheets) are exporting the environmental and social impact of these products to places like Brazil. The Brazilian government sees the country's combination of bauxite deposits and rivers capable of producing hydropower as an opportunity to exploit a competitive advantage in exporting aluminum (Ciccantell, 2005; de Andrade et al., 2001). The question is whether this represents a wise choice.

While dams being built by the Brazilian government produce power that is bought by aluminum smelters (at subsidized rates), "autoproduction," or building and ownership of dams by aluminum companies themselves, is also increasing (e.g., Bermann, 2004). Dams for autoproduction in Brazilian Amazonia are listed in Table 3. Note that the official figures for affected people given in Table 3 (International Rivers, 2012) may be significantly underestimated, especially for the Santa Isabel Dam (Mougeot, 1990, p. 98).

[Table_3_here]

Except for cases where dams are built and owned by the aluminum companies themselves, the association between particular dams and aluminum smelting is increasingly blurred as electricity in the country has become progressively more integrated since creation of the National Interconnected System (SIN) in 1995; all Brazilian states will be connected to the SIN by the end of 2015. The Tucuruí Dam, which blocked the Tocantins River in 1984, provides an example of a dam built primarily for aluminum (Fearnside, 1999, 2001; Pinto, 1997). In 1989, 49.9% of all electricity consumed in the state of Pará was by the Albrás smelter in Barcarena (Brazil, ELETRONORTE, 1987). In addition to a direct transmission line to Barcarena, Tucuruí also has a direct line to the Alumar smelter in São Luis in the state of Maranhão. Today the new dams connected to the SIN provide power to a national grid, from which smelters in various locations tap electricity. One result of the advent of the SIN is that proponents of hydroelectric dams can always claim that the power is going to the homes of the people of Brazil. In 2008 the residential sector accounted for 22.3% of Brazil's electricity use, while heavy industry (including aluminum) accounted for 28.6%, light industry 17.4%, commerce and services 14.6%, government 8.0%, energy 4.3%, agriculture 4.3%, mining 2.6% and transport 0.4% (Bermann, 2012a). The fact remains that electricity from the SIN used by aluminum companies is more than the output of even the largest of the many dams planned in the Amazon region.

In 2007 total consumption of electricity in Brazil was 412.1 TWh (Brazil, MME, 2009, p. 26), while use for primary aluminum was 25.13 TWh (ABAL, 2008, p. 48), or 6.1% of the total. In addition to primary aluminum (ingots), a growing form of export is as sheets or bars. Of course, the country also uses vast amounts of energy for other purposes. The explosion of Amazonian dams is clearly not driven by aluminum alone, and a broad reform of the country's energy policies is needed. Nevertheless, primary aluminum stands out because of this commodity's high impacts and meager benefits for Brazil. The possibility of large-scale expansion of aluminum exports is real, since global demand for primary aluminum is expected to increase greatly in the coming decades (Bergsdal et al., 2004). Unlike final products with final consumers in Brazil, potential global demand is essentially infinite from the standpoint of any given country, even one as rich in energy resources as Brazil. In other words, there is no natural stopping point where Brazil's rush to build ever more dams would be halted for lack of markets for aluminum and other electro-intensive commodities. Critical decisions, such as what kinds of products the country should export and whether to build scores of dams in Amazonia, need to be made in a rational and democratic fashion rather than being surrendered to the invisible hand of the global economy.

Aluminum and economic returns

Exported aluminum is exempt from Brazil's principal tax -- the Tax on Circulation of Goods and Services (ICMS). This is a result of the "Kandir Law" (Complimentary Law No. 67/1996). Since the aluminum smelters located in Amazonia are almost exclusively for export, they pay little tax, whereas those in the rest of the country, which primarily supply transformation industries for domestic consumption, pay much more. The "nominal" tax rates applying to the Amazonian smelters of Albrás and Alumar are estimated at 18% and 13% of gross receipts, respectively, but the "effective" tax paid (after discounting tax incentives and other benefits) is only 8% in both cases (Cardoso et al., 2011, p. 70). By contrast, Companhia Brasileira de Alumínio (CBA), located in the states of São Paulo and Minas Gerais, sells 71% of its production on the domestic market; its nominal tax rate of 21% is only slightly reduced to 20% as the effective rate (Cardoso et al., 2011, p. 71).

Brazil exported 404,848 t of aluminum ingots in 2013, worth US$789.9 million (ABAL, 2014, pp. 25 & 27). At 8% effective tax, this generated only US$63.2 million in revenue for the Brazilian government – a miniscule amount compared to the financial cost and damage inflicted by hydroelectric dams that underlie the industry.

Brazil's imports of aluminum have been increasing, including intermediate products such as sheets and rods (Table 4). Part of the supply of ingots and other untransformed forms of aluminum for transformation industries in Brazil's southeastern region comes from imports, mostly from Argentina. These imports account for 12.6% of the primary aluminum that is not exported in raw form (Table 4). Unlike smelters in southeast Brazil, the country's Amazonian smelters are dedicated to export; the main destination for ingots is Japan.

[Table_4_here]

Domestic consumption of aluminum has surged in Brazil since 2004, approximately doubling by 2013, and the industry expects further increase through 2020 (Massarente et al., 2013, p. 4). Exports continue to be dominated by ingots and other untransformed products: 80.8% of the exported weight is in this form, while another 12.3% is in semi-manufactured products and only 6.9% is in manufactured products (Table 4). The impact of the hydroelectric dams that sustain these exports is in proportion to their weight, not their value. The value of exports is also mostly in untransformed aluminum: 58.9% of the total (Table 4).

Aluminum and employment

The president of the Brazilian Association of Aluminum (ABAL) praises aluminum and hydroelectric dams "for the growth of Brazil" (Azevedo, 2011). The implication that smelting primary aluminum is contributing to the alleviation of poverty and unemployment in Brazil is misleading because the cost of producing the few jobs that are created by primary aluminum is sacrificing the opportunity for Brazil to use both its financial and the energy resources in other more-beneficial ways. Employment is minimal in primary aluminum production. In 2013, Brazilian smelters used 19,852 GWh of electricity and supported 28,928 direct jobs (ABAL, 2014, pp. 10 & 34). This represents only 1.46 jobs per GWh of electricity, even less than the 2.7 jobs/GWh calculated by Bermann and Martins (2000, p. 90).

Construction of the Belo Monte Dam, for example, involves estimated monetary costs totaling over R$40 billion [approximately US$20 billion at the time of the estimates]. This cost is the R$30 billion 2010 estimate of the construction firms for the dam itself, plus the R$5 billion contracted in 2014 for the first transmission line, plus R$7.7 billion expected for the second transmission line. In the case of Belo Monte, the choice is not between this dam and nothing, but rather between investing this amount of money in Belo Monte versus investing the same amount in something else. The cost of the decision to invest in Belo Monte is not only one of lost job-creation opportunities but also the significant environmental and social impacts on the Xingu River, both above and below the dam (e.g., Santos & Hernandez, 2009).

The employment numbers presented by the president of ABAL are aggregated in a way that makes aluminum appear to be better than it is. The employment figures given lump the smelting of primary aluminum with employment in "transformation" industries and in "indirect" jobs in the wider economy. ABAL's president claims 350,000 "direct and indirect" jobs (Azevedo, 2011). This is apparently an expansion of what is meant by "indirect" from the estimate for 2009 in ABAL's fourth (2010) sustainability report of 346,000 jobs described as "direct, indirect and recycling" (ABAL, 2011, p. 31). Of these, 130,000 are "direct and indirect" and 216,000 are in recycling (ABAL, 2011, p. 17). Particularly poignant is the inclusion of recycling in these figures. Brazil has some of the highest aluminum recycling rates in the world: for aluminum cans, 98.2% recycling is claimed (ABAL, 2011, p. 46). While this is undoubtedly a positive feature, it is less a reflection of green consciousness than of the country's economic inequalities: many poor people survive by retrieving aluminum cans from roadside rubbish and city dumps. These jobs, of course, would still be there even if no primary aluminum were produced in Brazil.

ABAL's 2013 Statistical Yearbook indicates 90,509 jobs in transformation industries, or three times more than the 28,928 jobs in smelting primary aluminum (ABAL, 2014, p. 10). ABAL (2014, p. 10) claims 382,449 "indirect" jobs. It should be recognized that "indirect" jobs cannot fairly be credited to aluminum, as any other form of investment would also create jobs when the money paid in salaries spreads through the surrounding communities to create jobs in commerce, services, etc. Indirect jobs are more-or-less proportional to the number of direct jobs created, which in the case of primary aluminum is extraordinarily low both in terms of jobs per unit of money invested in the industry and in terms of jobs per GWh of electricity consumed (Bermann, 2002; Bermann & Martins, 2000; Monteiro & Monteiro, 2007). Only the primary aluminum jobs are relevant to the debate surrounding new dams like Belo Monte.

ABAL claims "indirect" benefits from producing aluminum, but does not take responsibility for any impacts other than those within the walls of the aluminum factory itself. ABAL (2010) estimates greenhouse-gas emissions at 6.661 t CO_2-eq/ t of primary aluminum, or 0.15% of Brazil's national emissions. Unfortunately, the impact of the hydroelectric dams built to supply power to these factories is an integral part of the impact of aluminum smelting. Aluminum's high electricity consumption is even portrayed as an indirect *benefit* to Brazil in ABAL's 2010 sustainability report: "Did you know that... As the aluminum industry consumes high load electrical power during 24 hours/day, it provides important compensation for the hydroelectrical power generating system, contributing for the investment ability of the energy industry and its expansion" (ABAL, 2011, p. 37).

No one would suggest that Brazil should not produce aluminum for its own consumption, but defining what is "consumed" in the country is a slippery and easily manipulated label. Aluminum ingots that are exported are obviously not "consumed," but what about the next step up the chain: aluminum in the form or rods or sheets? This first transformation step produces some employment, but much less than the later manufacturing steps that will make consumer products out of these intermediate forms. Has aluminum been "consumed" in Brazil when intermediate products are produced and exported? The employment they generate is undoubtedly minimal compared to the financial, social and environmental impact of the hydroelectric dams that produce the main input to these products: the electricity used to smelt primary aluminum. Export products at the top of the chain, such as an airplane made of aluminum by EMBRAER, produce much benefit to the country that no one would want to lose. However, products like airplanes represent a miniscule part of the total aluminum exported by Brazil. All of the airplanes produced in 2011 (EMBRAER, 2012) multiplied by their respective empty weights represent a maximum of 3409 tons, assuming that they are composed only of aluminum. This represents only 0.2% of Brazil's approximate 2011 primary aluminum production of 1861 million tons (extrapolated from data available for previous years). Where the line is drawn between "consumption" and "export" has drastic effects on policy. Some shift in definitions may explain the unusual export numbers presented by ABAL (Azevedo, 2011).

ABAL indicates that 56% of the aluminum was being "consumed" domestically in 2007 (ABAL, 2008, p. 30), meaning that 44% was being exported as primary aluminum. In 2009 domestic consumption was 72% (ABAL, 2011, p. 31). The jump to 87% (1.3 out of 1.5 million tons) in 2010 presented by ABAL (Azevedo, 2011) probably represents acceleration of a trend to export more aluminum in forms slightly farther up the transformation chain (as opposed to being consumed by end users in Brazil). However, for aluminum produced in Amazonia this welcome trend appears not to apply. ABAL's data indicate the export destinations led by European countries (30.6%) followed by the USA (28.6%), Japan (22.2%) and others (18.6%) (ABAL, 2005, p. 20). The increase in Brazil's aluminum production from 2000 to 2008 (Bermann, 2012a) corresponds to a growth rate of 3.9% per year. The 2011-2020 energy expansion plan projects an annual production of 2.537 million tons by 2020 (Brazil, MME, 2011), which corresponds to an increase at 3.6% per year from 2008 to 2020. The 2012-2021 plan reduced this projection to 1.1% per year based on ABAL's claim that Brazil's electricity is more expensive than in competing countries (Brazil, MME, 2012, pp. 28 & 35).

As an illustration, Brazil could, if it wanted, import aluminum at any stage in the chain of production from primary aluminum ingots through the finished products. In 2009 Brazil imported 162 thousand tons of aluminum in the form of finished products or components, or 16% of the total "consumed" in the country (ABAL, 2011, p. 31). Imagine, for the sake of argument, that Brazil ceased producing primary aluminum altogether and imported sufficient ingots to supply all three groups: those who make aluminum products whose final consumers are in Brazil, those who make final products for export, and those who export intermediate products such as aluminum rods and rolled sheets. In this case the amount of employment in transformation and in final product manufacture would be the same as it is today. The difference lies in the cost of producing the primary aluminum domestically versus the cost of importing it. Since the real cost of producing primary aluminum is largely non-monetary, being in the form of social destruction in the places where hydroelectric dams are built, and in environmental impacts such as greenhouse-gas emissions, such a choice might not be so irrational for Brazil. The option is always open to produce only enough primary aluminum in Brazil to manufacture end products that are consumed inside the country, plus a few select high-benefit exports such as airplanes. The end of exports of raw ingots, of coils of aluminum rods and rolls of aluminum sheets, and of building materials, packaging and other lower-benefit products, would be a small price to pay compared to the destruction wrought by hydroelectric dams. The money saved from investment in dams and in the less-noble aluminum products could be invested in other industries with greater employment benefits than those provided by this portion of the aluminum chain and its associated hydroelectric industry.

The drawbacks associated with aluminum also apply to other electro-intensive commodities that are produced for export with power from Amazonian dams. Iron alloys produce even less employment than primary aluminum: 1.1 jobs per GWh consumed (Bermann & Martins, 2000, p. 90). Brazil produced 0.984 million tons of iron alloys in 2008 (Bermann, 2012a) and annual production is expected to grow to 2.060 million tons by 2020 (Brazil, MME, 2011), implying a growth rate of 6.4% per year. In 2008 iron alloy production consumed 7143.8 GWh, and primary aluminum 25,247.2 GWh (Bermann, 2012a). By 2020 electricity use for iron alloys would increase to 14,955.4 GWh and for aluminum to 38,562.4 GWh. The total for these two commodities in 2020 (53,518.6 GWh) corresponds to an increase at 4.2% per year since 2008. As a general rule across many countries, investment in primary commodities such as these produces significantly less benefit for national indicators of economic wellbeing than do other types of investment (Carmignani & Avom, 2010). The energy embodied in this trade is particularly important in the case of Brazil (Bermann, 2011; Machado et al., 2001).

Aluminum in the context of international markets

The international price of aluminum has risen and fallen over the course of recent decades, with logical impacts on the force of this commodity in driving dam-building decisions. These price cycles can be expected to continue in the future. During periods with attractive prices aluminum has been one of the motives (and in many cases the primary motive) for building some of the world's largest dams, which are also some with the largest environmental and social impacts. These include Brazil's Tucuruí Dam, Ghana's Akosombo Dam, Canada's James Bay dams, Venezuela's Guri Dam, and various dams in the Patagonian region of Chile (Gitlitz, 1993). The existing and planned Inga dams on the Congo River have had a long history of connection to aluminum, with a massive complex of smelters from various countries planned from the 1970s through the early 1980s, and then again in the 2000s prior to the 2008 financial crash (Misser, 2013). In addition to price fluctuations, political and military events in the Democratic Republic of Congo have impeded implementation of the plan (Misser, 2013). Nevertheless, the Congo is specifically mentioned by the International Aluminium Institute (IAI) as a likely site for future smelters (Nappi, 2013, p. 27).

Aluminum prices crashed dramatically from US$3000/ton to US$ 1250/ton with the global financial crisis in 2008; prices partially recovered to US$2750/ton by April 2011 and then declined to a plateau at around US$2000/ton by mid-2013 where they have remained through April 2015 (LME, 2015). Low prices have caused Brazilian smelters to postpone expansion. For example, in 2009 the 475,000-ton/year Votorantim smelter in Sorocaba, São Paulo put a planned 100,000 ton/year expansion on hold while at the same time investing in a new aluminum smelter in Trinidad and Tobago, where Chinese financing had been attracted with an offer of cheap electricity for 30 years from the country's abundant natural gas reserves (Ribeiro, 2009). Presumably, at some future date global demand will have risen sufficiently to make investments in smelters in Brazil and elsewhere attractive again.

The low prices affecting decisions in Brazil have similar effects throughout the world. In December 2013, a year after a memorandum of understanding had been signed with the Paraguayan government, Rio Tinto Alcan "postponed" a US$4 billion aluminum smelter in Paraguay that had been scheduled to begin operation in 2016 producing 674,000 tons per year (Reuters, 2013). This postponement was motivated by the low price of aluminum, combined with a "capacity overhang" of many aluminum smelters around the world due to China's unexpected move to smelt more of its own aluminum rather than importing it (Trefis, 2013). China's primary aluminum smelting increased from 2.7 million to 21.9 million tons/year over the 2000-2013 period, and further increased to 27.7 million tons/year in 2014 (IAI, 2015).

Projected global growth in demand for primary aluminum for 2013-2030 implies the equivalent of 40-50 new 500,000-ton/year smelters, plus additional smelters to replace some of the existing facilities that will be dismantled or idled over this period (Nappi, 2013, p. 26). Shifts in the locations of primary aluminum production are expected to be toward "regions where stranded energy can be available" (Nappi, 2013, p. 27). Among the factors expected to influence these shifts are restriction on CO_2 emissions from energy sources. Despite tropical dams not being "green" in terms of greenhouse gases (Fearnside, 2015a,b), this argument is likely to be used to favor movement of smelting capacity to Brazil and other tropical locations with hydropower potential, such as the Congo. China's shift to domestic smelting is particularly problematic in light of that country's recently announced commitment to reduce emissions after 2030 (e.g., Petherick, 2015). In 2013 China used 302,913 GWh of electricity in smelting primary aluminum, or 49.5% of the global total and ten times more than all of Latin America; 90% of the electricity China used for smelting aluminum in 2013 came from coal (IAI, 2015).

Aluminum in the context of Brazil's energy policy

Brazil needs to develop "alternative" sources of energy, but this is only a part of what is needed in energy policy. Energy efficiency comes before "alternative" sources. Improvements in transmission systems offer a major opportunity: Brazil's transmission losses of 20%, for example, are double the losses in Argentina (Rey, 2012). Increased energy efficiency in both residential and industrial use also offers major opportunities (Kishinami, 2012). Brazil's National Plan for Climate Change notes that 5% of the country's electricity is used to heat water with electric showerheads, the replacement of which is an official goal (Brazil, CIMC, 2008, p. 58). Much of Brazil's bathwater could be heated with solar water heaters without use of either electricity or fossil fuels (Costa, 2007).

First and foremost is the need for a thorough rethinking of energy uses and to what extent these uses are in the national interest. Recognizing the impacts of hydroelectric dams, particularly as compared to other options, represents a central part of this task. Hydroelectric dams have tremendous impacts, many of which are not widely known to the public at large and many of which are not considered, or not properly assessed, in the current system of environmental licensing in Brazil and in many other countries. The greater impacts and smaller benefits of hydropower, both as compared to the image that the hydroelectric industry and the Brazilian government have promoted and as compared to many other options (Moreira, 2012), provides a strong rationale for a change of course in Brazil's energy sector. These changes include elimination of low-value energy-intensive exports, encouragement of efficiency and investment in sources such as wind and solar power. An additional reason for pursuing alternatives to dams is concern that predicted climate change will significantly reduce the reliability of Amazonian hydropower (Kemenes et al., 2012).

Brazil's energy policy represents a set of problems of such scale and complexity that a common reaction is to assume that nothing can be done to change it. The key decisions are fragmented among different ministries: the Ministry of the Environment, which is the most concerned with environmental and social impacts of dams, has little influence on the Ministry of Mines and Energy, which promotes hydropower. The Ministry of Mines and Energy has little influence on the Ministry of Development, Industry and Commerce or the Ministry of Planning, Budget and Management, which promote aluminum export. Essentially, planning decisions are made under the assumption that the Ministry of Mines and Energy will build however many dams are needed to supply implied power demands and that the Ministry of the Environment will fix any environmental problems that ensue. The pattern of investing enormous sums of public funds in hydroelectric dams (through the National Bank for Economic and Social Development, or BNDES), and of the government and taxpayers assuming the risk associated with these uninsurable enterprises, contrasts with the modest amounts devoted to alternatives such as energy efficiency and generation from sources such as wind, solar and tidal resources.

Massive problems such as the reform of Brazil's energy policies can be broken down into more manageable components and addressed one at a time. Brazil "consumed" 500.1 TWh of electricity in 2012 (Brazil, MME, 2012, p. 38). In reality, part of this electricity is not "consumed" by end-users in Brazil, but is instead exported in electro-intensive commodities such as aluminum. A high-level decision not to export this is a good place to start. Other "wedges" in Brazil's growing energy problem must also be addressed, but this must not prevent action on each of the individual components of the problem, starting with aluminum.

The role of corruption

Because dam construction involves very large monetary sums, corruption is a factor that can easily become an endemic part of decision making on these projects. In investigating the contracts for Tucuruí, Lúcio Flávio Pinto (a prominent journalist) courageously made a series of charges of corruption against some of Brazil's most powerful individuals (Pinto, 1991, p. 143). Corruption accusations surrounding construction of the Itaipu Dam, shared by Brazil and Paraguay, similarly emerged after the dictatorships ended in these two countries in 1985 and 1986, respectively (Schilling & Canese, 1991). The Itaipu dam, built by military governments on either side of the Paraná River, was further protected from questioning by being entrusted to a specially created binational company that was exempt from the regulations on competitive bidding and financial accounting in either country. Corruption is believed to be an important factor for many dams throughout the world in countries such as Malaysia (BMF, 2015), China (Peryman, 2008), Nepal (Shenker, 2010), Ethiopia (Plummer, 2009), India (*Indian Express*, 2011), and in Laos and other Mekong countries (Stuart-Fox, 2006; *The Economist*, 2012).

Surely one of the world's most notorious cases of corruption in dam building is the Yacyretá Dam, located on the border between Argentina and Paraguay. Argentina's president Carlos Menem famously called the dam a "monument to corruption" (Christian, 1990). The World Commission on Dams claimed that by 1994 the amount stolen totaled US$6 billion (World Bank, 2003, p. 59). Much of the funding had been supplied by the World Bank, and the total lost to corruption was undoubtedly considerably more by the time the dam was finally completed in 2011, 31 years after its first World Bank loan (Rich, 2013, pp. 49-52). Part of the power from Yacyretá produces aluminum ingots, alloys and semi-manufactured products that Argentina exports to Brazil (Table 4). Paraguay incurred most of the social impacts, including displacing 50,000 urban poor; with a total of over 70,000 people displaced, less than 19,000 had any sort of resettlement arrangement before the reservoir was filled in 1994 (Rich, 2013, p. 50). Paraguay had no need for the electricity as such: beginning in 1985 the country's share of the output from the Itaipu Dam on the border with Brazil has been much more than Paraguay's total consumption, and most of Paraguay's share is sold to Brazil.

Data released by Brazil's Superior Electoral Court (TSE) show that the four largest contributors to electoral campaigns in Brazil between 2002 and 2012 were construction companies that build dams and other large infrastructure projects (Gama, 2013). Such contributions are extraordinarily profitable for the donating companies (Scofield Jr., 2011). Construction firms represented the largest sector contributing donations to the electoral campaigns of Brazil's current president, including two of the top three donors: Camargo Corrêa and Andrade Gutierrez (Zampier, 2010). It is relevant to note the March 2015 confession of the chief executive officer of Camargo Corrêa (Brazil's second-largest construction firm) that, in order to obtain 16% of the contracts for the Belo Monte Dam, the company paid "*propinas*" (bribes) totaling R$100 million (~US$50 million at the time of the contracts in 2010) (*Amazonas em Tempo*, 2015). If the other companies building Belo Monte paid in the same proportion, the total would be R$600 million or US$300 million for this dam, and Belo Monte is only one of various dams under construction Brazil's Amazon region.

Impacts of dams in Amazonia

Losses to flooding

The fact that land is flooded by reservoirs is obvious and is the focus of almost all consideration in environmental impact statements for dams in Brazil. The loss of land, and what could have been produced there had a dam not been built, is often substantial (e.g., Mougeot, 1990; Santos et al., 1996). Natural features can also be lost, the flooding of the Sete Quedas National Park by the Itaipu reservoir being the best-known example in Brazil. A current example is provided by the government's issuance of a provisional measure (*medida provisória*), later enacted as Law No. 12,678/2012, reducing areas of existing conservation units to make way for the first six dams proposed in the Tapajós River Basin (see: Bermann, 2012b; Fearnside, 2015c). In addition to forest loss to flooding, dams stimulate deforestation in surrounding areas (e.g., Barreto et al., 2011).

Dislocation of human populations represents an impact that, because it is largely non-monetary, has often received little weight in decisions on dam construction despite a repeated pattern of dams provoking dramatic suffering in affected areas (Cernea, 1988; Goldsmith & Hildyard, 1984, 1986; McCully, 2001; Oliver-Smith, 2009; Scudder, 2006; Zhouri, 2011). The Tucuruí Dam (completed in 1984 on the Tocantins River in Brazil's state of Pará) provides an example where 23,000 people were displaced by the reservoir and where settlement areas experienced dramatic problems related to agriculture, health and lack of infrastructure (Fearnside, 1999). The number of people to be displaced by the Belo Monte Dam on the Xingu River in Pará (where construction began in late 2011) is far greater than those who are recognized by electrical authorities (Santos et al., 2009). In part this is due to the practice of defining the affected population using criteria that consistently minimize the number of people identified as affected, in practice limiting them to those whose land is directly flooded by the reservoir (see: Hernandez & Santos, 2011; Vainer et al., 2009). The World Commission on Dams has conducted a worldwide review of resettlement from dams indicating widespread occurrence of major impacts from loss of homes and livelihoods (WCD, 2000, pp. 97-133). Were principles of environmental justice accorded more weight in Brazil's decision making, these considerations would count heavily against dams and aluminum.

How decisions are made that imply disrupting the lives of tens of thousands of people, often including indigenous peoples and other traditional riverside communities, is a matter of social justice. Monetary costs of hydroelectric dams may be spread throughout society by collecting taxes and by higher electricity bills, but most human and environmental impacts are forced upon the comparatively few people who happen to live along the river that is dammed. Usually these people are far away from those who will receive the benefits (WCD, 2000).

The decision to build a dam in Brazil is made by a handful of people in institutions such as Electrical Centers of Brazil (ELETROBRÁS), the National Bank of Economic and Social Development (BNDES) and the presidential office's "Civil House" (*Casa Civil*) (e.g., Fearnside & Laurance, 2012). While the licensing process may involve years of studies, hearings and "consultations," the decision to build the dam in question has already been made in a real sense (as opposed to a theoretical or legal sense). Those who will suffer the impacts have no voice or representation when the real decision is made (see examples in Fearnside, 1989, 1999, 2005a).

Downstream impacts

Impacts of dams go far beyond the area directly flooded by the reservoir. Downstream impacts are largely ignored (Richter et al., 2010). In the case of Belo Monte, people living downstream were considered not "directly" impacted (Brazil, ELETROBRÁS, 2009), and the government therefore does not provide indigenous people with the same rights to consultations as would apply in the area to be flooded (*The Economist*, 2013). The so-called "dry stretch" below Belo Monte is the result of that dam's design, which diverts 80% of the water to the side through a series of canals, to return to the river at a point approximately 100 km downstream (Brazil, ELETROBRÁS, 2009). Two indigenous areas are located in the long stretch of river in the "big bend" of the Xingu River that will have its water flow reduced to a minimal amount, thus depriving the indigenous people and other residents of the fish that are their main food source, as well as the river's role for transportation (de Sousa Júnior & Reid, 2010; Santos & Hernandez, 2009). Additional discussion of downstream impacts is included in the Supplementary Online Material.

Upstream impacts

Dams also block migration of fish, both ascending and descending the river (Barthem & Goulding, 1997). Many species of fish in Amazonia have a "*piracema*," or a mass migration ascending the tributaries in order to breed at the beginning of the flood season (Barthem et al., 1991). After breeding in the headwaters, the newly-born fish drift down these tributaries with the current and then grow to adulthood in the mainstem of the Amazon River (Carvalho & Fabré, 2006). This was the case for the large catfish such as dourada (*Brachyplatatystoma rouxeauxii*) and piramutaba (*B. vaillantii*) that ascended the Madeira River to spawn in Bolivia and Peru (Barthem & Goulding, 1997; Barthem et al., 1991). With 920 species, the Madeira was one of the rivers most richly endowed with fish in Brazil and in the world (Torrente-Vilara et al., 2013). The giant catfish of the Madeira River had traditionally represented a significant economic and dietary resource in the Brazilian portion of the river (Doria et al., 2012; Goulding, 1979). They also supported fisheries in Bolivia and Peru, including the fishing fleet at Puerto Maldonado, Peru (Cañas & Pine III, 2011). Fish passages around these dams have virtually no chance of maintaining this fish migration ascending the river, nor of preventing mortality of the newly born fish descending the river (Fearnside, 2014a). Additional discussion of upstream impacts is included in the Supplementary Online Material.

Mercury

Mercury contamination can be one of the environmental and social costs of hydroelectric development in Amazonia. Use of mercury in gold mining has released hundreds of tons of mercury into the environment in Amazonia (Bastos et al., 2006, 2015; de Lacerda et al., 1989; Pfeiffer & de Lacerda, 1988). The source of mercury can be gold mining done directly in the reservoir area, such as the mining that occurred in the area recently flooded by the Madeira River dams and in areas planned for dams on the Tapajós River and its tributaries (Boischio et al., 1995; Forsberg & Kemenes, 2006; Pfeiffer et al., 1991). However, mercury inputs from gold mining activity are not necessary to have contamination, and reservoirs in areas without a history of gold mining also have high levels of mercury, as at Balbina (Kashima et al., 2001; Kehring et al., 1998; Weisser, 2001). Because the soils in Amazonia are ancient, they have been accumulating mercury over millions of years as dust from volcanic eruptions around the world settles over the landscape (Roulet & Lucotte, 1995; Roulet et al., 1996). Additional discussion of mercury is included in the Supplementary Online Material.

Dam cascades

Another aspect of dams with major impacts that escape the current environmental licensing process is the interconnection with other existing or planned dams on the same river (Fearnside, 1999, 2001). This is an important difference from other types of electrical generation, where each plant is independent of other plants. Output of the downstream dams is increased by regulating water flows in a river, storing water during the high-water period and releasing it during the low-water period (e.g., Nilsson et al., 2005). This stored water generates electricity multiple times – once at the upstream dam, and again at each downstream dam. This creates an embedded temptation to build more dams upstream of any dam being evaluated for licensing. In the case of the Tucuruí Dam, which, in 1984, was the first in the Tocantins/Araguaia watershed that covers much of southern Pará and northern Mato Grosso, a total of 26 dams were planned (Junk & de Mello, 1990). Of these, four have since been built (Table 1) and seven are planned (Table 2) in the portion of the basin that is in the Legal Amazon region. Planned projects include the Marabá Dam, which will displace 40,000 people (Rodrigues & Ribeiro Junior, 2010).

The extreme case is Belo Monte, where the Belo Monte Dam itself has a small storage capacity (virtually zero in active storage) relative to its installed capacity of 11,233 MW. The volume of water in the Xingu River varies so much over the annual cycle that the 11,000 MW of the main powerhouse will be completely idle for approximately four months each year, and only partially used for much of the remainder. This is the root of the wider danger posed by Belo Monte, as Belo Monte by itself is untenable without the water stored in the upstream dams that were publically proposed until 2008 when the declared policy changed to claim that Belo Monte would be the only dam on the Xingu River (e.g., de Sousa Júnior & Reid, 2010). This claim was made in a decision of the National Council on Energy Policy (CNPE), which is composed of ministers who change with each presidential administration.

Additional discussion of dam cascades is included in the Supplementary Online Material.

Hydropower and global warming

The Brazilian Association of Aluminum (ABAL) claims in its 2011 sustainability report that "Our aluminum is 'green' at the source, as it originates from clean and renewable energy" (ABAL, 2011, p. 4). Unfortunately, hydroelectric dams in Amazonia emit greenhouse gases, particularly methane (CH_4). Dams in the humid tropics emit more CH_4 than do those in other climatic zones (Barros et al., 2011; Demarty & Bastien, 2011). Dams produce methane because the water in a reservoir stratifies into layers, with a warm layer (epilimnion) in the upper 2-10 m of water that is in contact with the air and contains oxygen, and a cold layer (hypolimnion) at greater depth where oxygen is quickly exhausted and decomposition of organic matter must end in CH_4 rather than CO_2 (Fearnside & Pueyo, 2012). Some of the methane generated escapes to the atmosphere as bubbles through the surface of the reservoir, and if the reservoir is large relative to the volume of water passing through the dam, as at Balbina, this surface emission can be substantial (Kemenes et al., 2007). A smaller amount escapes by diffusion, particularly in the first year or two after filling the reservoir (e.g., Dumestre et al., 1999). However, what gives most tropical reservoirs their greatest impact on global warming is the water that passes through the turbines and spillways (e.g., Abril et al., 2005). This water is drawn from well below the boundary (thermocline) that separates the layers of water in the reservoir, and normally has high concentrations of methane (Fearnside, 2002). The water deep in the reservoir is under pressure, which is immediately released as the water emerges from the turbines (Fearnside, 2004). The solubility of gases decreases immediately when the pressure is released, and solubility decreases further as the water gradually warms in the river below the dam (Le Chatalier's Principle) (e.g., Battino & Clever, 1966; Joyce & Jewell, 2003). Much of the methane forms bubbles and is released immediately. The effect of releasing the pressure is the same as occurs when one opens a bottle of a soft drink and CO_2 that had been dissolved escapes as bubbles (see Fearnside, 2004). The impact of tropical dams on global warming has often been underestimated, especially by the hydropower industry (see Fearnside, 2015b).

ABAL's president supported his claim that hydroelectric power is "clean" energy by referring to studies by the FURNAS hydropower company indicating "100 times less carbon" being emitted by a dam that is six to ten years old, as compared to generating the same amount of electricity from fossil fuels (Azevedo, 2011). Various problems make this a misleading portrayal, particularly for the Belo Monte Dam that ABAL defends as "clean energy" (Azevedo, 2011) (Table 5).

[Table_5_here].

It is significant that ABAL casts aside any information from the notorious Balbina Dam, calling this dam that flooded a vast area in exchange for very little energy a "mistake committed in the past" that "doesn't reflect the reality of tropical lakes" (Azevedo, 2011). Unfortunately, Balbina is very relevant to Belo Monte and other planned dams. The methodologies for methane estimation do not depend on whether the decision to build the dam was a mistake. Balbina was, indeed, a tragic mistake that was obvious before that dam became a *fait accompli*; unfortunately, many of the features of the decision-making process that led to the dam's construction are still evident today

(Fearnside, 1989, 2006). Other aspects of the Balbina experience are relevant: upstream of Belo Monte the dam that is best known as "Babaquara" (although it has officially been renamed "Altamira," apparently in an attempt to minimize the effect of years of criticisms of the plans) would have an area of 6140 km^2, or more than double that of Balbina. The reservoir would have a 23-m vertical variation in the water level, making it a tremendous "methane factory" (Fearnside, 2008, 2009, 2011). The ABAL text suggests that high greenhouse-gas emissions in Amazonian dams are restricted to Balbina (where directly measured emissions exceed those of fossil fuels decades after the dam was built in 1987: Kemenes et al., 2007, 2008). However, high emissions have also been directly measured at the Petit Saut Dam in French Guiana (e.g., Abril et al., 2005; Guérin et al., 2006) and they have been calculated based on available data at the Tucuruí, Samuel and Curuá-Una Dams in Brazil (Fearnside, 2002, 2005a,b). Although there is substantial variation among dams both in their emissions and in the amount of power they produce, the pattern of Amazonian dams producing higher emissions than fossil fuels over long periods is, indeed, quite general. In the case of Belo Monte plus Babaquara, the time needed to break even in terms of greenhouse gas emissions has been calculated at 41 years (Fearnside, 2009). This is based on the conversion of CH_4 to CO_2-equivalents from the second report of the Intergovernmental Panel on Climate Change (IPCC), used in the Kyoto Protocol; subsequent revisions have greatly increased the impact of methane relative to CO_2, and therefore the impact of dams relative to fossil fuels (see Table 5). The impacts of upstream dams in flooding large areas of tropical forest in indigenous lands, in addition to producing methane, make Belo Monte and the aluminum produced from its power anything but clean.

It should be remembered that power for aluminum production is not exclusively produced by dams. When reservoir levels are low, aluminum factories are supplied from thermoelectric power plants. These emit greenhouse gases among other impacts.

Environmental licensing of dams

Environmental licensing of dams in Brazil proceeds through a sequence of steps, beginning with a "preliminary license" (allowing preparations to begin and specifying conditions to be met), followed by an "installation license" (allowing the dam to be built), and finally an "operating license" (allowing power generation to begin). The licensing of Belo Monte occurred under intense pressure from Brazil's presidential office, and the process was facilitated by recent precedents set by similar forced approval of the Madeira River dams (Fearnside, 2013, 2014b). Although the president of ABAL stated with reference to Belo Monte and other Amazonian dams that "the environmental agencies duly granted the licenses after the projects had fulfilled all of the demands made on them" (Azevedo, 2011), Belo Monte had and continues to have a long list of irregularities in its licensing by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA, the federal environmental agency). First, the construction site was prepared on the strength of a "partial license," granted by IBAMA on February 1, 2010 (see ISA, 2010). This is a category of license that does not exist in Brazilian legislation (it was invented by IBAMA when it granted a provisional license to the Madeira River Dams on July 9, 2007, allowing these dams to move forward before completing their environmental impact assessments: See Switkes & Bonilha, 2008). On January 26, 2011 Belo Monte received a preliminary license from IBAMA, which specified 40 "conditionalities" that would have to be met before an Installation License would be granted, plus an additional 26 conditionalities from

FUNAI (the agency for indigenous peoples) (see ISA, 2011a). Very little was done over the ensuing months to fulfill these conditionalities (see: Xingu Vivo, 2011).

On June 1, 2011 the dam was granted an Installation License even though the IBAMA technical staff had recommended against approval (Brazil, IBAMA, 2011; ISA, 2011b). The head of the agency was suddenly replaced and the new appointee immediately granted the license. Only five of the 40 IBAMA conditionalities had been fulfilled at the time of the licensing according to non-governmental organizations and 16 according to IBAMA; approval without satisfying all conditionalities creates a dangerous precedent for projects throughout the country. As of February 2014, almost three years after the Installation License was approved, the consortium building the dam had only complied with three of the 19 conditionalities involving indigenous peoples (ISA, 2014). This situation continues essentially unchanged and is being monitored by a group of non-governmental organizations (FGV, 2014). The value of a "conditionality" becomes questionable if project developers can have a license from IBAMA without fulfilling the requirement. In addition, at the time the new head of IBAMA signed the Installation License no less than 12 legal suits against Belo Monte were still pending decisions in the courts over irregularities in the licensing process (the number grew to 20 by November 2013). Legal documentation on these can be consulted at http://www.xinguvivo.org.br/. Proceeding with construction without resolving these issues risks damaging Brazil's democratic institutions because the large investments of financial and political capital make the executive branch of government unlikely to cancel the project if the judicial branch makes such a ruling (Fearnside, 2012). Although Brazil's licensing system is in evident need of reform, the current dominance of the "ruralist" anti-environmental voting block in the National Congress means that legislative initiatives to strengthen the system would instead be seized upon to further weaken it; this limits the scope for improvement to efforts in other branches of government and in civil society (Fearnside & Laurance, 2012).

Global implications

Global dam-building activity is increasingly focused on tropical areas in Africa, Southeast Asia and Latin America. National decisions on promoting and subsidizing dams and electro-intensive exports have multiple perverse effects on political processes in developing countries through the "resource curse" and other mechanisms. Decisions on export priorities and on energy policies give little weight to the heavy environmental and social costs of dam projects, as is evident in the example of Brazil. Such decisions may partly be the result of decision makers' lack of information about these impacts, but they also fit the adage that "no noise is loud enough to wake someone who is pretending to be asleep."

Conclusions

Dam building around the world is driven by electricity demand, including that for electro-intensive commodities like aluminum. The decisions of countries to build dams is often based on systematic underestimation of the monetary, social and environmental impacts of dams and exaggeration of their benefits as compared to other options, such as energy conservation, alternative generation sources and forgoing energy exports in products like aluminum.

One of the ways that Brazil could reduce the destruction from Amazonian dams would be to stop exporting aluminum in the form of ingots or products (either intermediate or final) that do not have a high benefit in terms of direct employment per unit of electricity consumed in the product's full production chain, including the smelting of primary aluminum. The benefits of aluminum have often been exaggerated, while the impacts of dams have been understated. Primary aluminum is the worst form in which this metal can be exported in terms of employment generation per gigawatt-hour of electricity consumed, but other products farther up the chain of transformation are also unattractive when the energy use of the primary aluminum from which they are made is included in the accounting. In addition to decisions on aluminum exports based on realistic assessments of the impacts of dams and the benefits of aluminum, Brazil needs broader reforms of its energy projections and policies in order to enjoy the uses of energy that increase wellbeing while not destroying the forests, rivers and societies of Amazonia.

Amazonian hydroelectric dams have impacts that are much more severe and wide-ranging than what has been portrayed by dam proponents. Social impacts are devastating for the people who happen to live in the area of a dam, including not only those in the flooded area but also those downstream and upstream of the dam who lose vital resources such as fish. Indigenous peoples and other traditional riverside residents (*ribeirinhos*) are often the victims. Environmental impacts extend to the entire river basin, including changes from altered sediment and water flows as well as loss of aquatic fauna and loss or disturbance of vast areas of forests, *várzea* (floodplain) and other ecosystems. Tropical dams also emit substantial quantities of greenhouse gases, often exceeding the cumulative emissions of fossil fuel generation for decades. For all of these reasons, hydropower is far from being "green" energy, and Brazil needs to make rapid changes in energy policy to curtail the announced expansion of Amazonian dams.

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Figure legends

Fig.1. Existing dams and dams in the planning or construction phases in Brazil's Legal Amazon region. The numbers of the existing dams (dams with their reservoirs filled by February 2014 indicated by circles) correspond to the numbers listed in Table 1, and the numbers of the dams that are planned or under construction (indicated by triangles) correspond to the numbers listed in Table 2. Adapted from: Fearnside (2014c).

Fig. 2. Locations mentioned in the text. 1. Itaipu Dam, 2. Manso Dam, 3. Jirau Dam, 4.Santo Antônio Dam, 5. Samuel Dam, 6. Balbina Dam, 7. Petit-Saut Dam, 8. Curuá-Una Dam,9. Belo Monte Dam, 10. Babaquara (Altamira) Dam, 11. Tucuruí Dam, 12. Marabá Dam, 13. Serra Quebrada Dam, 14. Santa Isabel Dam, 15. Estreito Dam, 16. Serra da Mesa Dam. Circles represent dams; triangles represent cities.

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Highlights

Decisions on dams ignore the high impact and low benefit of aluminum exports.

Were impacts given appropriate weight, policies on dams and exports would change.

Dams impact global warming, local populations, indigenous peoples and biodiversity.

Electricity is the principal input for aluminum smelting.

Table 1: Existing* dams in Brazil's Legal Amazon region (Updated from: Fearnside, 2014c)

No. in Fig. 1	Year filled	Name	State	River	Installed capacity (MW)	Area of reservoir (km^2)	Coordinates
1	1975	Coaracy-Nunes	Amapá	Araguari	78 [298 MW by 2016]	23 (for initial 78 MW)	00°54'24" N; 51°15'31" W
2	1977	Curuá-Una	Pará	Curuá-Una	100	78 (for initial 40 MW)	02°49'11.49" S; 54°17'59.64" W
3	1984	Tucuruí	Pará	Tocantins	8370	2850	03°49′54″ S; 49°38′48″ W
4	1987	Balbina	Amazonas	Uatumã	250	2996	01°55′02″ S; 59°28′25″ W
5	1987	Manso	Mato Grosso	Manso	212	427	14°52'16" S; 55°47'08" W
6	1988	Samuel	Rondônia	Jamari	210	560	08°45'1" S; 63°27'20" W
7	1999	Lajeado (Luis Eduardo Magalhães)	Tocantins	Tocantins	800	630	09º45'26" S; 48º22'17" W
8	2006	Peixe Angical	Tocantins	Tocantins	452	294	12°15'02" S; 48°22'54" W
9	2011	Dardanelos	Mato Grosso	Aripuanã	261	0.24	10°09'37" S; 59°26'55" W
10	2011	Santo Antônio (Madeira)	Rondônia	Madeira	3150 by 2015	350	08°48'04.0" S; 63°56'59.8" W
11	2011	Rondon II	Rondônia	Comemoração	73.5	23	11°58'51" S; 60°41'56" W
12	2012	Estreito (Tocantins)	Maranhão/ Tocantins	Tocantins	1087	744.68	06º35'11" S; 47º27'27" W
13	2013	Jirau	Rondônia	Madeira	3750 by 2015	361.6	09º15'17.96" S; 64º 38' 40.13" W
38	2014	Santo Antonio do Jari	Pará/Amapá	Jari	167	31.7	00°39' S; 52°31' W
46	2014	Teles Pires	Mato Grosso	Teles Pires	1819	151.8	09°20'35" S; 56°46'35" W

*Dams > 30 MW with reservoirs filled by May 2015.

Table 2 – Dams under construction and planned in Brazil's Legal Amazon region (Updated from: Fearnside, 2014c).

No. in Fig. 1	Name[a]	State	River	Installed Capacity (MW)	Reservoir area (km^2)	Status	Expected year of completion	Coordinates
14	Água Limpa	Mato Grosso	Das Mortes	320	17.9	Planned	2020	20'53" S; 53°25'49" W
15	Babaquara [Altamira]	Pará	Xingu	6,300	6,140	Officially unmentioned		03°18'00" S; 52°12'30" W
16	Belo Monte	Pará	Xingu	11,233	516	Under construction	2016	03°6′57″ S; 51°47′45″ W
17	Bem Querer	Roraima	Rio Branco	708	559.1	Planned	2022	01°52'40" N; 61°01'57" W
18	Cachoeira Caldeirão	Amapá	Araguari	219	48	Planned	2017	00°51.2'00" N; 51°12'00" W
19	Cachoeira do Caí	Pará	Jamanxim	802	420	Planned	2020	05°05'05" S; 56°28'05" W
20	Cachoeira dos Patos	Pará	Jamanxim	528	117	Planned		05°54'59" S; 55°45'36" W
21	Cachoeirão	Mato Grosso	Juruena	64	2.6	Planned		12°59'22" S; 58°57'29" W
22	Chacorão	Pará	Tapajós	3,336	616	Officially unmentioned		06°30'08" S; 58°18'53" W
23	Colíder	Mato Grosso	Teles Pires	300	171.7	Under construction	2015	10°59'5.9" S; 55°45'57.6" W
24	Couto Magalhães	Mato Grosso/Goiás	Araguaia	150	900	Planned		18°12'35" S; 53°3'06" W
25	Ferreira Gomes	Amapá	Araguari	252	17.72	Preliminary license	2015	00°51'20.126" N; 51°11´41.071" W
26	Foz do Apiacás	Mato Grosso	Apiacás	45	89.6	Planned	2018	09°12'23" S; 57°05'11" W
27	Ipueiras	Tocantins	Tocantins	480	933.5	Planned		11°15'11" S; 48°28'53" W
28	Jamanxim	Pará	Jamanxim	881	75	Planned	2020	05°38'48" S; 55°52'38" W
29	Jardim de Ouro	Pará	Jamanxim	227	426	Planned		06°15'49" S; 55°45'53" W
30	Jatobá	Pará	Tapajós	2,338	646	Planned	2021	05°11'48" S; 56°55'11" W
31	Juruena	Mato Grosso	Juruena	46	1.9	Planned		13°24'05" S; 59°00'27"W
32	Marabá	Pará	Tocantins	2,160	1,115.4	Planned	2021	05°19' S; 49°04' W
33	Magessi	Mato Grosso	Teles Pires	53		Planned		13°34'35" S; 55°15'54" W,
34	Novo Acordo	Tocantins	Sono/Tocantins	160		Planned		09°58'25" S; 47°38'23" W
35	Ribeiro Gonçalves	Maranhão /Piauí	Paranaíba	113	238	Planned	2018	07 °34'31"S; 45°19'02"W
36	Salto Augusto Baixo	Mato Grosso	Juruena	1,464	107	Planned	2021	08°53'6.3" S; 58°33'30.1" W

	[JRN-234b]							
37	Santa Isabel (Araguaia)	Pará	Araguaia	1,080	236	Planned		06°08' 00" S; 48°20' 00" W
38	Santo Antonio do Jari	Pará/Amapá	Jari	370	31.7	Now filled, see Table 1	2014	00°39’ S; 52°31’ W
39	São Luiz do Tapajós	Pará	Tapajós	8,040	722	Planned	2020	04°34'10" S; 56°47'06" S
40	São Manoel	Mato Grosso	Teles Pires	700	53	Planned	2018	09°11’29”S; 057°02’60”W
41	São Salvador	Tocantins/Goiás	Tocantins	243.2	99.65	Under construction		12°48'45" S; 48°15'29" W
42	Serra Quebrada	Maranhão	Tocantins	1,328	420	Preliminary license	2020	05°41'52" S; 47°29'11" W
43	Simão Alba [JRN-117a]	Mato Grosso	Juruena	3,509	> 1,000	Planned	2021	08°13'33.5" S; 58°19'23.9" W
44	Sinop	Mato Grosso	Teles Pires	400	329.6	Preliminary license	2018	11°16'10" S; 55°27'07" W
45	Tabajara	Rondônia	Ji-Paraná	350		Planned	2021	08°54'15" S; 62°10'21" W
46	Teles Pires	Mato Grosso	Teles Pires	1,819	151.8	Now filled, see Table 1	2015	09°20’35” S; 56°46’35” W
47	Tocantins [Renascer]	Tocantins	Tocantins	480	700	Planned		16°47'10” S; 47°56'31” W
48	Toricoejo	Mato Grosso	Das Mortes	76	48	Preliminary license		15°14'05" S; 53°06'57" W
49	Torixoréu	Mato Grosso/ Goiás	Araguaia	408	900	Preliminary license	2023	16°16'59" S; 52°37'00" W
50	Tupirantins	Tocantins	Tocantins	620	370	Planned		08°10'59" S; 48°10'00" W
51	Uruçuí	Maranhão /Piauí	Paranaíba	164	279	Preliminary license		07°14’08” S; 44°34’01” W
Not shown	Castanheira	Mato Grosso	Arinos	192			2021	
Not shown	Arrais	Tocantins	Palma	70			2022	
Not shown	Prainha	Amazonas	Aripuanã	408			2022	
Not shown	Paredão A	Roraima	Mucujaí	199			2023	

[a]Dams included in Brazil's 2014-2023 Energy Expansion Plan are: Santo Antônio do Jari [now filled], Belo Monte, Colíder, Ferreira Gomes, Teles Pires [now filled], Sinop, Cachoeira Caldeirão, São Manoel, São Luiz do Tapajós, Jatobá, Bem Querer, Paredão A, Arrais, Castanheira and Tabajara. The last four are recent additions to the priority list. Dams that had been scheduled for construction by 2021 that have now been postponed beyond 2023 are: Ribero Gonçalves, Água Lima, Simão Alba, Marabá and Salto Augusto Baixo (Brazil, MME, 2012, pp. 77-78). Dams that have postponed from previous plans but are scheduled for completion by 2023 are: Belo Monte, Bem Querer, Foz de Apiacás, Jatobá, São Luiz do Tapajós, São Manoel and Sinop. Several dams have had their installed capacities increased, most notably São Luiz do Tapajós from 6133 to 8040 MW.

Table 3. Dams for autoproduction of aluminum in Brazilian Amazonia

No in Fig. 1	Dam	Rjver	Status	Affected people*	Comment
12	Estreito	Tocantins	Existing	5,937	Partially for autoproduction
42	Serra Quebrada	Tocantins	Planned	14,000	
37	Santa Isabel	Araguaia	Planned	2,378	

*Source: International Rivers (2012).

Table 4. Aluminum in Brazil in 2013[a]

		Production Weight (1000 t)	Imports Weight (1000 t)	Consumption Weight (1000 t)	Exports				
					Weight (1000 t)	Value (US$ million)	Price (US$/t)	Percent of exported weight	Percent of Exported value
Untransformed metal									
	Ingots	1,304.3	50.3		404.8	789.9	1,951.00	76.4	55.4
	Alloys		79.5		15.1	34.7	2,292.71	2.9	2.4
	Scrap	470.7	39.3		8.1	15.2	1,879.66	1.5	1.1
	Subtotal	1,775.0	169.1	12.6	428.0	839.7	1,961.73	80.8	58.9
Semi-manufactured products [b]									
	Sheets	542.9	78.5	579.7	42.3	125.9	2,977.75	8.0	8.8
	Cables and rods	140	2.8	134.8	6.7	16.3	2,433.01	1.3	1.1
	Foil	87.2	22.2	93.8	16.3	64.4	3,940.05	3.1	4.5
	Subtotal	770.1	103.6	808.3	65.3	206.6	3,162.60	12.3	14.5
Manufactured products									
	Extruded products	357.8	17.3	367.5	7.2	51.6	7,209.96	1.4	3.6
	Powder	33.8	0.4	34.0	0.2	0.7	4,416.56	0.03	0.05
	Household products	42.0	5.4	40.8	6.5	52.3	7,986.96	1.2	3.7
	Castings	223.9		230.9	9.6	173.8	18,032.71	1.8	12.2
	Other	25.3	31.4	31.0	13.0	100.5	7,755.43	2.4	7.1
	Subtotal	682.8	54.5	704.2	36.5	378.9	10,391.42	6.9	26.6

Destructive uses	40.8		40.8					
Totals	(c)	332.9	1512.5 (d)	529.9	1,425.2	2,689.37	100.0	100.0

(a) Source: ABAL, 2014: Production (pp. 13 & 30), imports (p. 21), exports (p. 27), consumption (p. 30).

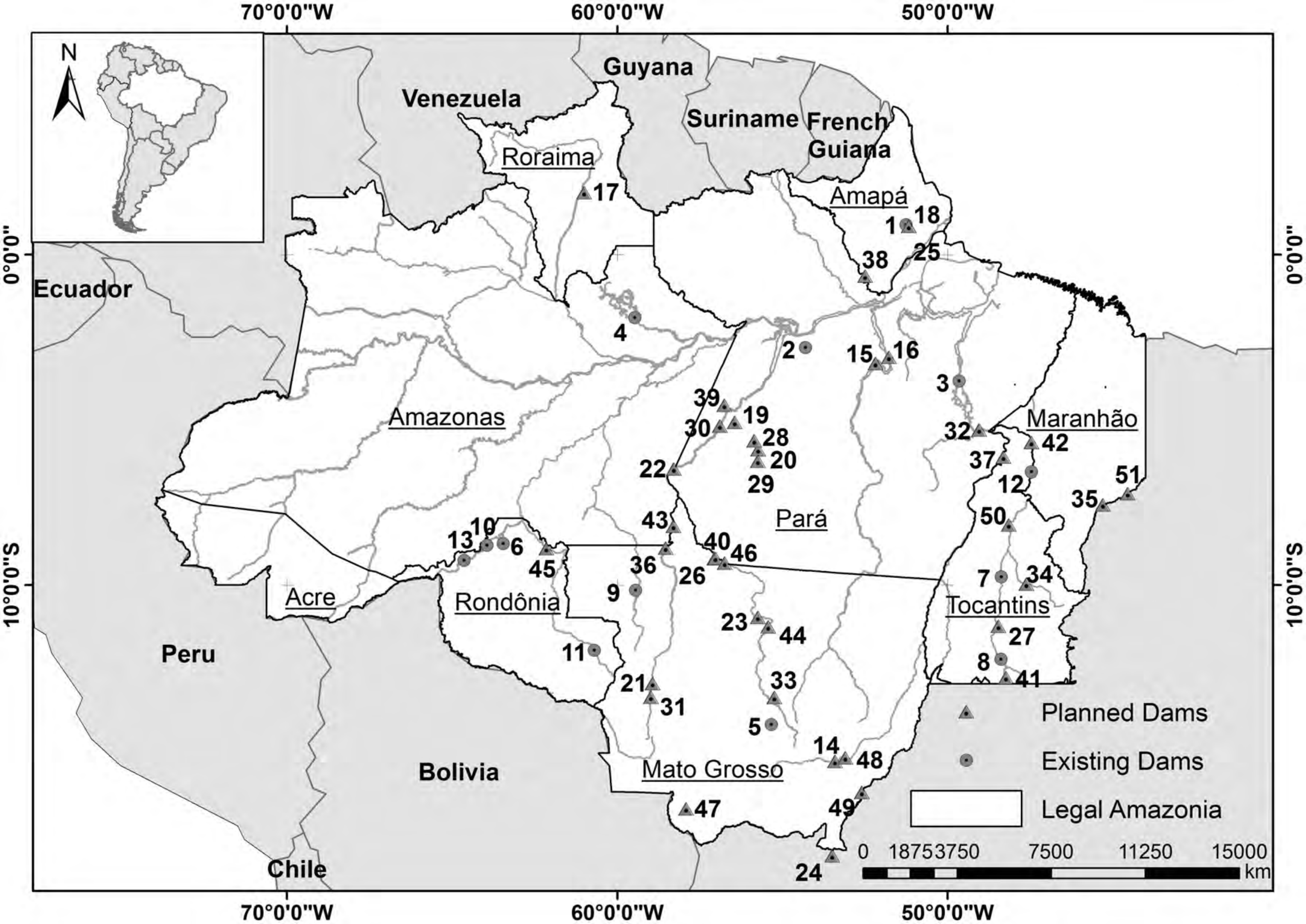
(b) Production deduced from consumption, exports and imports.

(c) Note that prodution cannot be totaled, since products in the semi-manufactured category are made from untransformed metal, and those in the manufactured category are made from the preceding two categories.

(d) This is the consumption total given by ABAL, representing the sum of the subtotals for semi-manufactured and manufactured products. However, this probably includes some double counting because some manufactured products are made from semi-manufactured products.

Table 5. Hydropower as "clean" energy in the view of the Brazilian Association of Aluminum (ABAL) on the Belo Monte Dam.

ABAL claim	Problem
Dams in FURNAS study have low carbon emissions.	The FURNAS refers to dams outside of Amazonia: the study was done on the Manso and Serra da Mesa Dams in the *cerrado* (Central Brazilian savanna) biome, where dams have lower emissions than in rainforest areas. Belo Monte and the great majority of planned dams are in Amazonia (Brazil, MME, 2012, pp. 77-78).
Dams 6-10 years old have low emission	The age of six to ten years mentioned by the president of ABAL in referring to the dams in the FURNAS study is significant because hydropower produces a huge peak of emission in the first few years – a debt that can take decades to pay off as the electricity generated gradually offsets emissions from thermoelectric plants. The implication of the ABAL statement is that this debt is simply forgiven by only comparing the instantaneous balance in year six or ten.
"Reservoir" emissions are low	"Reservoir" emissions refer to those from the surface of the water impounded behind the dam. The FURNAS study alluded to by ABAL used a methodology that did not measure most of the methane being released by water passing through the turbines. This water is the main source of methane emission (e.g., Abril et al., 2005). The FURNAS study (Ometto et al., 2011, 2013) measured downstream methane fluxes using chambers floating on the water surface some distance below the outlet to the turbines (at least 50 m downstream). Unfortunately, much of the methane comes out of the water immediately at the outlet or even inside the turbines themselves. The only practical way to quantify the emission at the turbines is by the difference between the methane concentration in the water above the dam (at the depth of the turbines) and below the dam.
Dams have low "carbon" emissions as compared to thermal power	"Carbon" is not the issue, but rather the impact on global warming. A ton of carbon in the form of methane (CH_4) emitted by a dam has much more impact than a ton of carbon in the form of carbon dioxide (CO_2) emitted by fossil fuels. Considering the global-warming potential (GWP) of 25 for methane gas (Forster et al., 2007) adopted by the Clean Development Mechanism for the 2013-2017 period, meaning that each ton of methane gas has the impact of 25 tons of CO_2 gas over a 100-year period, then each ton of carbon emitted to the atmosphere as methane has the impact of 9.1 tons of carbon as CO_2. If one considers feedbacks, the most recent report of the Intergovernmental Panel on Climate Change (IPCC) calculates the 100-year GWP of CH_4 as 34 (Myhre et al., 2013), meaning each ton of methane carbon has 12.4 times the impact of a ton of CO_2 carbon. The same IPCC report also calculates a GWP of 86 for a 20-year time horizon that is more relevant to preventing global mean temperature increase from passing the 2℃ limit now agreed as "dangerous," making each ton of carbon 31.3 times as potent if in the form of CH_4.



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60°0'0"W
50°0'0"W
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Venezuela
Suriname
French Guiana
Roraima
Amapá
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Ecuador
Amazonas
Pará
Maranhão
Acre
Rondônia
Tocantins
Peru
Bolivia
Mato Grosso
Chile
10°0'0"S
Planned Dams
Existing Dams
Legal Amazonia
0
1875
3750
7500
11250
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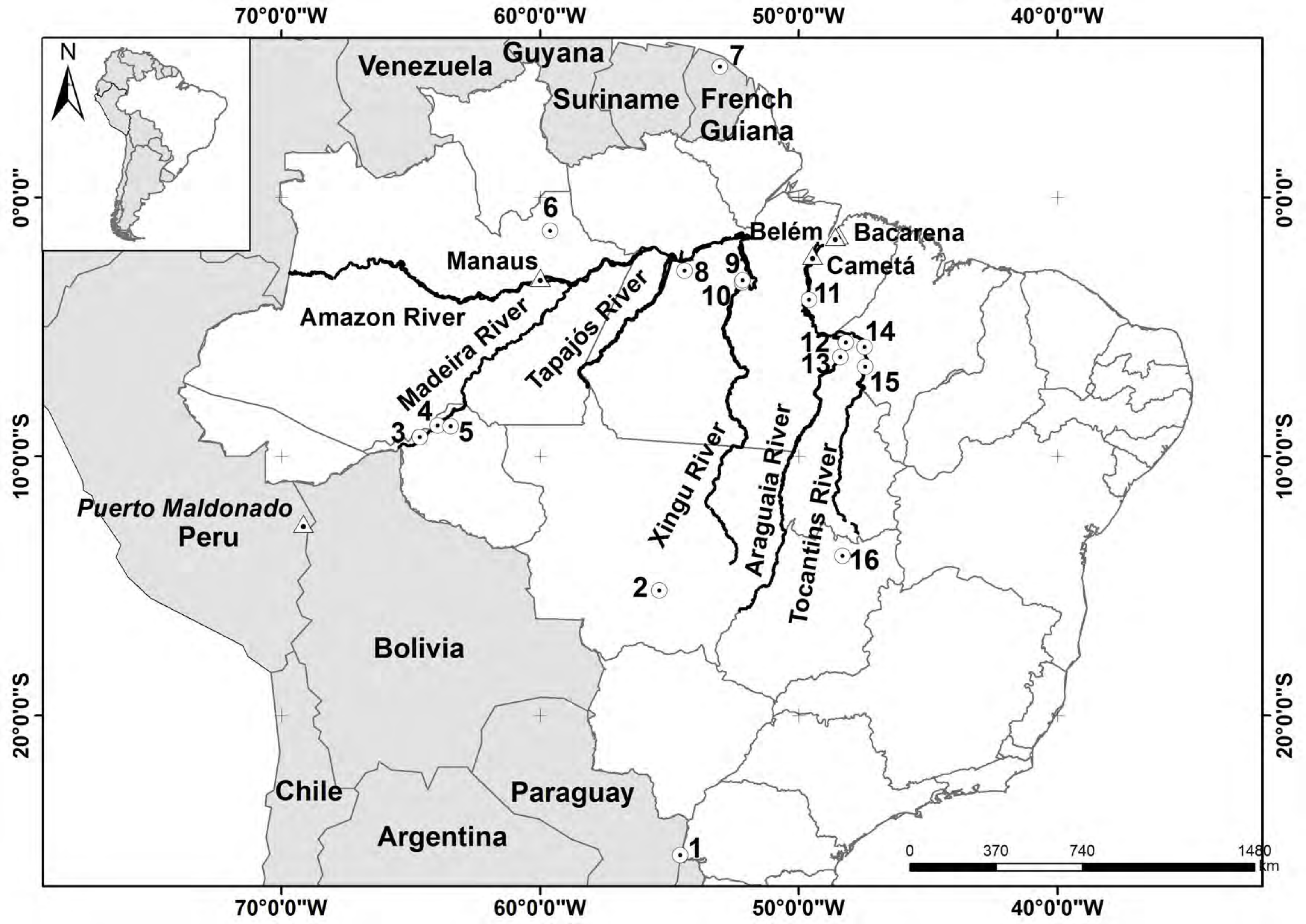
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0°0'0"
10°0'0"S
20°0'0"S
N
Venezuela
Guyana
Suriname
French Guiana
Manaus
Belém
Bacarena
Cametá
Amazon River
Madeira River
Tapajós River
Xingu River
Araguaia River
Tocantins River
Puerto Maldonado
Peru
Bolivia
Chile
Paraguay
Argentina
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
370
740
1480
km

Supplementary Online Material:

Environmental and Social Impacts of Hydroelectric Dams in Brazilian Amazonia: Implications for the Aluminum Industry

Downstream impacts

Downstream impacts are considerable even when dams do not create a “dry stretch” by diverting water flow to a new route, but rather have the more-common design where the water is released at a powerhouse located directly below the dam. The water passing through the turbines is drawn from near the bottom of the reservoir at a depth where the water contains almost no oxygen (Fearnside, 2002). Depending on factors such as the entry of significant tributary streams, water often must flow for great distances below a dam before it regains the amount of oxygen that would be found in the natural river (e.g., Gosse et al., 2005; Kemenes et al., 2007). The water without oxygen kills many fish and keeps others from entering the river from below, as in the case of fish ascending Amazon tributaries (de Almeida-Val et al., 2006). The consequence for the livelihoods of downstream residents is dramatic, and these impacts are completely unrecognized and uncompensated in existing dams. The Tucuruí Dam provides a clear example. In Cametá, the largest of five riverside towns on the lower Tocantins River (180 km downstream of Tucuruí), the fish catch fell by 82% and the freshwater shrimp catch fell by 65% between 1985 and 1987 (Odinetz-Collart, 1987; see Fearnside, 2001). Fish landings in Cametá, which were 4726 t/year in 1985 (Odinetz-Collart, 1987), continued to decline, stabilizing at an average of 284 t/year for the 2001-2006 period (Cintra, 2009, p. 97), or a loss of 94%. Just the loss of fish in Cametá is greater than the entire mean fish catch of 4078 t/year in the Tucuruí reservoir over the 2001-2006 period (Cintra, 2009, p. 97). Most of the fishing fleet at Cametá simply disappeared after the river was dammed. The same occurred with the fishing fleet at São Sebastião do Uatumã, over 200 km below the Balbina Dam (see Fearnside, 1989).

The flood pulse on undammed Amazonian rivers is an essential feature of almost all aspects of natural *várzea* (floodplain) ecosystems, as well as the agriculture that depends on annual renewal of soil fertility by sediments deposited by the floods (e.g., Junk, 1997). This pulse is also essential for nutrient inputs to *várzea* lakes, where many species of fish breed (including commercially important species). Reducing this pulse is a concern, for example, for *várzea* lakes along the Madeira River downstream of the Santo Antônio and Jirau Dams. The river below these dams (which began generating power in 2011 and 2013, respectively) was not considered to be part of the area of influence for environmental impacts (FURNAS et al., 2005).

Upstream impacts

Impacts upstream of hydroelectric reservoirs also include raising river levels in what is known as the “backwater stretch” (*remanso superior*). When a river enters a reservoir at its upstream end, the speed of the water flow immediately drops to a much slower rate, causing sediment in the water to sink to the bottom. Large particles such as sand settle to the bottom of the reservoir immediately, while fine silt settles near the dam at the lower end of the reservoir (Morris & Fan, 1998). This is especially important in a river like the Madeira, which has one of the highest sediment loads in the world (Meade, 1994). The large deposit at the upper end of the reservoir forms a mound that acts like a second dam holding back the water upstream and raising the water level in the backwater stretch—outside of what is officially considered to be part of the reservoir. This is critical in the case of the Madeira dams because the reservoir of the Jirau Dam officially extends exactly to the border with Bolivia, but the backwater stretch would flood land in Bolivia, including part of a conservation unit (Molina Carpio, 2005). The backwater stretch was not included in the environmental impact studies (EIA-RIMA) for the Madeira dams (FURNAS et al., 2005). In the flood of 2014 the presence of the Jirau Reservoir cause a 1-m additional increase in the water level at the border, thus causing flooding in Bolivia in the backwater stretch (Vauchel, 2014).

Mercury

Gold mining in the reservoir catchment area can also be a potential source of mercury, as in the case of the Serra Pelada mining area upstream of Tucuruí. Transport to the reservoir is mainly by water rather than through the atmosphere, and mercury is estimated to be accumulating in the Tucuruí reservoir at a rate of 235 kg year^{-1} (Aula et al., 1995).

Soil erosion in deforested areas carries organic matter and associated mercury into Amazonian rivers, increasing mercury levels in sediments (Roulet et al., 2000). Atmospheric deposition includes contributions from industrial sources around the world, including the burning of coal (Zhang et al., 2002), as well as from biomass burning in Amazonia (Veiga et al., 1994).

Sediments at the bottom of a reservoir are without oxygen and provide an ideal environment for methylation of mercury, or adding a methyl (CH_3) group to metallic mercury (Hg) (Huguet et al., 2010). This is what renders it highly poisonous (Tsubaki & Takahashi, 1986). Chemically, the process is similar to methanogenesis, or formation of methane (CH_4), which also occurs under the same anoxic conditions (Kelly et al., 1997). When a reservoir is flooded, in the first few years there is a large flush of bacterial methylation of accumulated mercury that is associated with soil organic matter; this has been observed throughout temperate and, especially, boreal zones (Joslin, 1994; Rosenberg et al., 1995). Following this initial peak, long-term accumulation in fish can be sustained by more modest rates of methylation in plankton (St. Louis et al., 2004) and biofilms (Huguet et al., 2010). Although contamination levels vary depending on water chemistry and other factors at each site, observations in Brazilian reservoirs indicate that this is also a general problem in tropical areas. In terms of human impact, favorability of sites for methylation often overshadows the importance of large stocks of metallic mercury: areas without gold mining can have high contamination in humans since amounts found in samples of fish and human hair vary in accord with water chemistry, rivers with low pH and high dissolved organic carbon having highest levels (Silva-Forsberg et al., 1999).

Mercury lies dormant in the soil in a harmless form, but the situation changes immediately when soil is flooded by a reservoir (e.g., Joslin, 1994). Mercury concentrates in fish, with the amount increasing with each step in the food chain, for example by 2 – 4 fold per trophic level in Tucuruí (Porvari, 1995). Tucunaré (*Cichla ocellaris* and *C. temensis)*, a predator, is the dominant fish species in Amazonian reservoirs and has been found to have mercury levels that greatly exceed international health standards for human consumption in the cases of Tucurui (Porvari, 1995; Santos et al., 2001) and Samuel (Malm et al., 1995). Humans are the next step in the food chain. At Tucuruí, lakeside residents consuming fish had higher mercury levels than those of gold miners in the Amazonian *garimpos* that are notorious for mercury contamination (Leino & Lodenius, 1995). Cytogenetic damage and a variety of motor deficiencies and reduced lateral vision, which are the first symptoms of Minamata disease (mercury poisoning), have been measured in Amazonian riverside populations (Amorim et al., 2000; Lebel et al., 1998). The primary factor keeping mercury contamination from having a more widespread impact in Brazil is low fish production of reservoirs (e.g., Cintra, 2009; Junk & de Mello, 1990). Contamination is therefore largely concentrated in local populations near the reservoirs, far from the country's centers of political power (see Fearnside, 1999, 2005a). While the environmental-justice issue this implies should add to the weight of negative factors in dam-building decisions, in practice the spatial distribution of impacts makes them easier for decision makers to ignore.

Dam cascades

Various indications strongly suggest that the investors in Belo Monte (and key government officials in the electrical sector) have no intention of following the CNPE policy. The lack of economic viability of Belo Monte without upstream dams is believed to be the key to a "planned crisis," where the need for more water would suddenly be "discovered" after Belo Monte is built, thus providing justification for approval of the other dams (de Sousa Júnior & Reid, 2010; de Sousa Júnior et al., 2006). The water shortage would be aggravated further by changes in the Xingu River's flow due to continued deforestation in the watershed (Panday et al., 2015; Stickler et al., 2013) and due to projected climate change (Kemenes et al., 2012). Another indication that the official scenario is fiction is that when Marina Silva, as Minister of the Environment, proposed creation of an extractive reserve in part of the area to be flooded by the upstream dams, the proposal was blocked by Dilma Rousseff [Brazil's current president] when she was head of the Civil House on the grounds that it would hinder dam construction upstream of Belo Monte (Angelo, 2010). As president, she has called for future dams to have "large reservoirs" rather than run-of-river designs, although without making an explicit reference to the Xingu River (Borges, 2013). The dams that were planned upstream of Belo Monte from 1975 to 2008 would flood vast areas of indigenous land, almost all of it under tropical rainforest (see Fearnside, 2006). None of this was considered in the EIA-RIMA completed in 2009 (Brazil, ELETROBRÁS, 2009), and was also excluded from the earlier version prepared in 2002 (Brazil, ELETRONORTE, nd [2002]).

Two major river systems are expected to have cascades of dams for a different reason: rather than to store water for generating electricity at downstream dams, the dams would have to go forward as a complete set in order to convert the rivers into navigable waterways known as "*hidrovias*." This applies to the four Madeira River Dams (two of which have been built so far) that would open 4000 km of waterways in Bolivia plus the Guaporé waterway that would connect the Madeira River to soy areas in Mato Grosso (Fearnside, 2014a). The other case is the Tapajós River Dams in Pará, including those on the Teles Pires and the Juruena Rivers (two tributaries in Mato Grosso) (Fearnside, 2015a). The planned waterways would carry soybeans to ports on the Amazon River (Brazil, MT, 2010). In the Madeira and Tapajós cases some (but not all) of the dams are "run-of-river" projects that depend on the natural flow of the river rather than on releasing stored water. The Tocantins/Araguaia Dams, which also are part of a planned waterway, are storage dams.

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