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Brazil's Belo Monte: A Cost-Benefit Analysis

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I. ABSTRACT

This paper analyzes the costs and benefits of Brazil's Belo Monte hydroelectric dam complex. We also provide a historical and technological introduction to Belo Monte. The cost and benefit analysis begins with a careful consideration of inputs, and includes a discussion of both quantifiable and unquantifiable costs and benefits. Finally, an analysis of Belo Monte's net present value across seven distinct scenarios and across a range of discount rates is conducted. Our paper finds that Belo Monte is very unlikely to be a positive net present value project over a time horizon of fifty years.

II. INTRODUCTION

Goal

The goal of this paper is to consider the costs and benefits of the Belo Monte Dam in Brazil. Though a significant source of renewable energy and arguably a necessary project if Brazil's economic growth is to be sustained, the dam's positives are diminished by its high upfront costs and its associated, and significant, political, environmental and social costs. After an introduction to the dam and its technology and a consideration of the aforementioned costs and benefits, we will conduct an analysis of Belo Monte's net present value across seven scenarios and a range of discount rates to determine under what scenarios Belo Monte is likely to have a positive or negative net present value.

Please note that we use an exchange rate of 2.57 Brazilian reals (R$) per US dollar ($) for the entirety of the paper.

The Basics

The Belo Monte Dam is currently under construction in the northern Brazilian state of Pará. Situated on the "Big Bend" of the Xingu River (a major tributary of the Amazon), Belo Monte is due to become the world's third largest hydroelectric dam complex in terms of installed capacity[1]; its maximum output of 11,233 megawatts (MW) will place it

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[1] Installed capacity (also known as nameplate capacity or rated capacity) is maximum output or, in other words, power production during ideal circumstances.

behind only the Itaipu Dam on the Brazil Paraguay border and the Three Gorges Dam in China[i]. The vast majority of this generating capacity – a full 11,000 MW – will come from the main power station situated alongside the namesake dam[ii]. However, two other dams are central to the production of electricity at the Belo Monte station. Pimental, the largest of the three, is located about 60 km upstream of Belo Monte and diverts much of the Xingu into the Canals Reservoir from which Belo Monte draws its water[iii]. Pimental also contains the auxiliary power station that supplies the remaining 233 MW[iv]. Bela Vista, the third and final dam, acts as the Reservoir's spillway[v]. That is to say, along with Pimental, Bela Vista helps control water levels. Throughout this paper, we use "Belo Monte" to refer to the entire complex, as well as the supplementary dykes and canals, unless specified otherwise.

Figure 2.1[vi]: The "Big Bend" of the Xingu River

Baseline Figure: Average Power Production

Although the installed capacity of Belo Monte is 11,233 MW, the dam will actually produce, on average, 4,571 MW of power[vii]. That is to say, Belo Monte's projected capacity factor[2] is 40.7%. Many opponents of the dam note this figure with dismay. Although this number may seem low, Table 2.1, which presents the capacity factor of Belo Monte relative to certain geographical averages and to the only four existing dams with installed capacities over 10,000 MW, shows that this is not necessarily the case.

Table 2.1: Belo Monte's Capacity Factor vs. The World

	Capacity Factor
Belo Monte	**40.7%**
Three Gorges (China)[viii]	46%
Itaipu (Brazil-Paraguay)[ix]	75%
Xiluodo (China)[x]	47%
Guri (Venezuela)[xi]	52%
Brazilian Average[xii]	56%
Latin American Average[xiii]	54%
World Average[xiv]	44%

[2] A capacity factor is simply a ratio consisting of actual output divided by installed capacity over some given amount of time (for us, this time period is a year).

While Belo Monte's capacity factor is over 10% lower than the Brazilian and Latin American average capacity factors, the Brazilian average is calculated using all dams with an installed capacity over 30 MW and the Latin American average is calculated using dams of all sizes[xv]. Therefore, since smaller dams tend to have much larger capacity factors, comparing Belo Monte to these figures does not seem particularly apt. When comparing Belo Monte with the other dams in the world that have an installed capacity over 10,000 MW, we see that Belo Monte still has a low capacity factor (especially when compared to Itaipu), though the difference is not quite as glaring. For hydroelectric dams, capacity factors can be influenced by water availability, equipment, and how the hydroelectric power is employed (for instance, is the energy only supplied during peak hours, or is it base-load generation). In the case of Belo Monte, water availability plays the largest role. One reason for this is that the dam is meant for base-load supply – it is meant to be a constant contributor to the electricity grid. Naturally, dams designed to produce electricity for peak hours will have lower capacity factors, but since Belo Monte is primarily designed for base-load generation, this cannot be what is driving down the capacity factor. Often, water issues are solved through reservoirs that help stabilize the flow of water and through careful surveys of the land and water. Though Belo Monte includes a large reservoir, it seems to be the case that the river flow is such that, even with the reservoir, the capacity factor is relatively low. Still, when compared to the other large capacity dams, Belo Monte's capacity factor is not quite as dismal as on first sight.

Finally, given the dam's capacity and its average power production 4,571 MW, we calculate the total energy produced by Belo Monte in a year. We will assume that the dam runs 24 hours a day for 360 days per year (i.e. the availability factor of the dam is 98.6% due to maintenance, extremely low water flows, etc. – this figure is consistent with general hydroelectric plants). Therefore, the total energy produced by the dam in a year is equivalent to 39,493,440 MWh.

Table 2.2: Key Figures

Belo Monte Average Power Production	**4,571 MW**
Annual Energy Produced by Belo Monte	**39,493,440 MWh**

Belo Monte's Past: A Brief History

Historical perspective is important when trying to understand the general significance and controversy of the Belo Monte Dam. Though this section is lengthy, the reader will find some historical understanding useful when reading later sections of this paper.

<u>Beginning and Failure</u>

The possibility of a major hydroelectric dam near the village of Belo Monte do Pontal was first identified between 1975 and 1979, when a hydrographic study funded by Eletrobras, a government majority-owned power utility company and the largest power

utility company in Latin America, listed the site as one of six on the Xingu River for potential development[xvi]. The key feature of the Belo Monte site was the "Volta Grande" or "Big Bend" of the Xingu River. The 140 km "Bend" sees the river's elevation fall by 93 meters (a sizeable drop in Amazonia) and provides the opportunity to cut a relatively short and direct path from upstream to downstream[xvii]. Such considerations are vital when designing dams, as is discussed in 'Dam Technology'.

In 1987, eight years after this initial study, Eletrobras officially released its "2010 Plan," which mapped out the construction of 297 dams across Brazil by 2010, including the six on the Xingu River[xviii]. However, the Xingu dams faced major opposition. Spearheaded by the indigenous Kayapo people, whose lands bordered much of the Xingu and who felt threatened by the fact that the dams would flood their lands and disrupt the river ecosystem that was vital to their way of life, opponents of the Xingu dams made the Brazilian governments' efforts known to the world. In fact, Kayapo leaders, outraged by the Brazilian government's disregard for their civil rights, met with members of the US Congress and the World Bank in 1987, eventually convincing the Bank to deny the Brazilian government a loan that was earmarked for the construction of the Xingu dams[xix]. The opposition to the dams culminated with the five-day "Altamira Gathering" of 1989, where around 500 Kayapo people, as well as farmers and other opponents of the dams, gathered to protest and hold a media conference[xx]. The event shined an international spotlight on the Brazilian government. Pope John Paul II sent a telegram of support to the Kayopa people. The rock star Sting spent a day in Altamira showcasing his commitment to the Kayopa. Other members of the "Gathering" included a British

Member of Parliament and a Belgium Member of the European Parliament[xxi]. Within two weeks of the "Altamira Gathering," and with the World Bank refusing to grant Brazil the loan, the Brazilian National Congress announced that it would conduct a formal investigation of the Xingu dams[xxii]. The final result was a shelving of five of the six dams Eletrobras had planned to build on the Xingu River. The only remaining dam was the one at Belo Monte, and even Belo Monte was to be subject to further review.

Between 1989 and 2002, Eletronorte (a subsidiary of Eletrobras in charge of power generation and distribution in northern Brazil), slowly and discretely revived the idea of a Belo Monte Dam Complex[xxiii]. The dam was redesigned, Eletronorte increased its political activity in the state of Pará, new environmental impact assessments were made, and, when low waters at existing dams led to an electricity supply and distribution crisis in the spring of 2001, Belo Monte was once more considered as a potential solution[xxiv].

However, it was not until Luiz Inácio Lula da Silva became Brazil's president in 2003 that the second attempt at building Belo Monte Dam succeeded. Early in his term, President Lula made it clear that one of his main goals was to complete many of the country's stalled infrastructure projects[xxv]. Much of the focus was directed at 18 hydroelectric dams, with Belo Monte the foremost of them. In 2005, the Brazilian National Congress passed legislative decree 788, which authorized construction of the Belo Monte Dam, subject to the approval of the relevant environmental and financial agencies[xxvi]. The Senate passed the decree within three days of it being passed by the house – an unheard of level of expediency for the National Congress[xxvii]. Moreover, since

the environmental and financial agencies are part of Brazil's executive branch, it was widely expected that they would support President Lula's direction, and that the building of Belo Monte was a foregone conclusion.

Second Time's a Charm

In 2008, a new environmental assessment by Eletrobras led to more design changes, specifically the addition of the Canals Reservoir in order to avoid the flooding of indigenous lands. In 2010, the Brazilian environmental agency, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), granted a partial preliminary license, the first of the three necessary licenses, to the project and, later that year, Norte Energia, a consortium 49% owned by Eletrobras and 75% stake-owned by government institutions as a whole, won the project auction[xxviii]. However, Norte Energia's winning bid of R$77.97/MWh was more than 6% cheaper than the price ceiling of R$83/MWh, which many potential bidders balked at as economically unfeasible [xxix]. Unsurprisngly, the bid itself was thus subject to much scrutiny. Indeed, the Brazilian Federal Attorney General's Office investigated the bid, and eventually suspended the partial preliminary license granted by IBAMA on the grounds that partial licenses were not permitted under Brazilian law[xxx]. However, a regional appellate court overruled this decision and, in August of 2010, President Lula and Norte Energia signed a contract for the construction of the Belo Monte Dam[xxxi].

Nonetheless, licensing issues for the dam did not stop with the signing of the agreement between Lula and Norte Energia. In January 2011, the full preliminary license was

granted by IBAMA, but it included 40 “mitigation actions” that Norte Energia would need to take before the second license, the installation license that is necessary to start construction, would be granted[xxxii]. The then President of IBAMA, Abelardo Bayma Azevedo, was particularly adamant about these “mitigation actions” and refused to grant Norte Energia a full installation license as he maintained that the project was rife with environmental problems that were not being properly addressed. Under heavy political pressure from the administration of President Rousseff (who succeeded Lula in 2011 and continued many of Lula’s infrastructure policies), Azevedo was forced to resign in January 2011. The new IBAMA president was appointed in February of that year and, by June, he granted the installation license to Norte Energia under the condition that the consortium would spend $1.9 billion to address the social and environmental issues noted by Brazil’s National Indian Foundation (FUNAI)[xxxiii].

From the granting of the full installation license in June 2011 to the present day, Belo Monte has been embroiled in a series of lawsuits, protests, suspensions of work, and strikes. In October 2011, for instance, 600 members of 21 indigenous tribes occupied the Belo Monte work site and had to be intimidated into leaving by military police[xxxiv]. Combinations of students, NGOs, farmers, and fishermen have held similar protests, and clashes ranging from blocking ferries from transporting machinery down the Xingu River to occupying the roads that lead to the work site have occurred. Workers, unhappy with working conditions and pay, have revolted and held strikes on multiple occasions as well, even burning down parts of the Pimental construction site in March 2013. There have been prostitution and human trafficking scandals, detentions of Norte Energia engineers

by indigenous tribes, and even a November 2013 European Parliament conference on the topic of Belo Monte[xxxv].

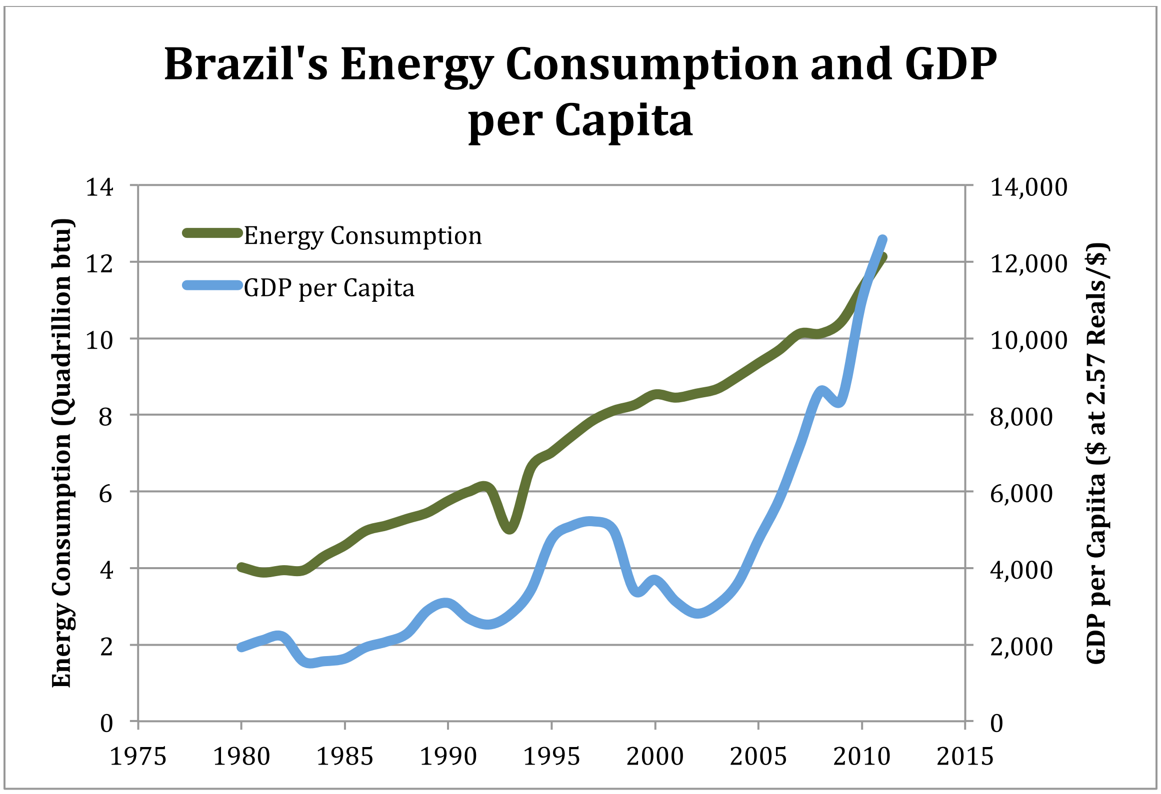
Perhaps the most significant event since the granting of the installation license, however, occurred on August 14, 2012, when a Brazilian federal appeals court ordered all construction of the dam to be halted[xxxvi]. The indigenous people of the region claimed that the Brazilian National Congress and Norte Energia had not properly consulted them regarding the project before construction began. A clause in the Brazilian constitution, derived from the International Labour Organization's Convention 169 (of which Brazil is a signatory), required such consultation[xxxvii]. Living next to the part of the river whose flow the Pimental Dam restricts (up to about 80% of the water's previous flow is diverted into the Canais Reservoir), the indigenous tribes claimed dependence on the water. The indigenous tribes' case was endorsed by, among others, the Human Rights Commission of the Organization of American States and the Brazilian Public Ministry (a branch of the Ministry of Justice)[xxxviii]. However, the Chief Justice of the Brazilian Supreme Court, Carlos Ayres Britto, unilaterally overturned the appeal court's ruling and work was thus allowed to resume after only about a week's pause[xxxix]. This ruling, more so than anything else that has occurred over the lifetime of the Belo Monte Dam, captured the importance of the project for the Brazilian government. Belo Monte is a huge financial and political capital investment by the executive branch of the Brazilian government – it is important enough to have pressured the judiciary into what was, by most accounts, a controversial decision, one that was viewed by many as making a mockery of the democratic process.

Despite all the issues, construction of the Belo Monte Dam has lumbered on. Roads have been built, over a "Panama-Canal's worth" of soil and rock has been excavated, dams are slowly being erected, and around 20,000 workers (a population larger than almost 75% of Brazil's 5,600 municipalities) are working virtually day and night to make the hydroelectric complex a reality[xl]. The auxiliary powerhouse, though three-months behind schedule, is expected to start producing energy in May 2015, while the main station at Belo Monte is projected to have its turbines gradually started up between 2016 and 2019[xli]. More outrage, problems, and hiccups will certainly occur, but one thing is clear: the second time around has been a charm. Belo Monte is currently over 50% complete, and the Brazilian executive branch will see the Belo Monte Dam project to the end[xlii].

Energy Consumption in Brazil

As Figure 2.2 shows, Brazil's energy demand grew at an average rate of 3.85% between 1980 and 2011 (the US's energy consumption, by comparison, grew at an average of 0.5%). From 2000 to 2010, energy consumption increased by a little over 30%. This huge increase in energy consumption coincided with the emergence of Brazil as a strong developing economy and with the shift of tens of millions of Brazilians out of poverty[xliii].

Figure 2.2[xliv]



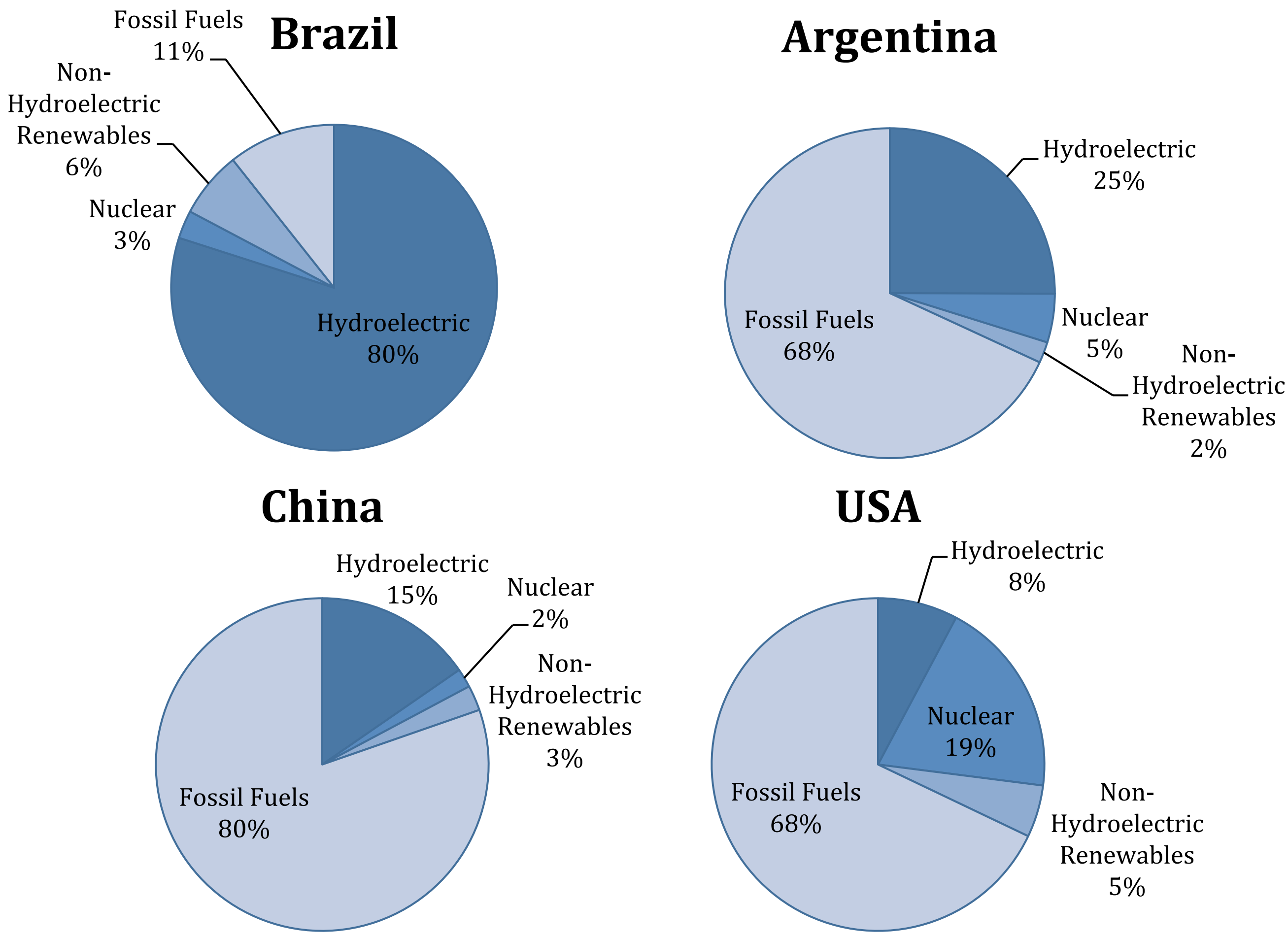
Though economists are generally split on the relationship between economic growth and energy consumption, there are many findings that point to the fact that the relationship differs from country to county. In some nations, GDP seems to have a causal relationship with energy consumption. In others, the inverse is true. In general, developing countries seem to have a less pronounced causal relationship in both directions and, the richer they become, the stronger this causal relationship becomes[xlv]. In Brazil specifically, researchers have shown that there is a bidirectional strong Granger causality between energy consumption and GDP[xlvi]. These last two facts imply that Brazil's reliance on energy consumption as an input for economic growth has been steadily increasing over the past two decades, and that Brazilian energy consumption lead to increases in GDP (the inverse also holds true for Brazil).

What is clear is that Brazil's energy demand has rocketed. In 2012, it was projected that Brazil would be able to satisfy its energy demands only if it added 6,350 MW of installed capacity per year for the next ten years. Given Brazil's 2012 installed generating capacity of 121,000 MW, this means that Brazil needs to increase its installed capacity by just under 50% by 2021[xlvii]. A dam like Belo Monte, with its installed capacity of 11,233 MW of production, therefore supplies about 17.6% of the necessary increase in installed capacity.

Brazil's Electricity Production: A Hydroelectric Focus

To better understand the importance of hydroelectricity in Brazil, it is helpful to look at what percentage of total electricity produced in Brazil comes from hydroelectric sources. As Figure 2.3 shows, an astonishing 80% of Brazil's produced electricity is generated hydroelectrically. To get a better sense of just how much that is, we can look at what the relative hydroelectric production is in a series of other countries – Brazil's neighbor Argentina, fellow member the "BRIC" China, and the USA. It is clear that Brazil is much more dependent on hydroelectric power than these countries (in fact, there is only one country in the world with a higher percentage of hydroelectricity production: Norway). Of course, the fact that Brazil is hydroelectricity-reliant does not speak to whether or not the Belo Monte Dam will have a positive net value. However, it does showcase the fact that Brazil is a country willing to make use of its hydroelectric potential, comfortable with hydroelectricity, and in a class of its own when it comes to the production of hydroelectricity.

Figure 2.3[xlviii]: Distribution of Electricity Produced in 2011



III. DAM TECHNOLOGY

As has been mentioned, Belo Monte is comprised of three dams. The main dam, Belo Monte, has a turbine house capable of generating 11,000MW, and this power capacity comes from 20 Francis turbines, each with an expected capacity of 550-660MW. The secondary dam, Pimental, contains seven Kaplan bulb turbines, each with a power capacity 25.9MW[xlix]. This section will highlight how the turbines work, what their expected efficiency is, and why they are so popular.

There are three main kinds of turbines used around the world: Pelton, Kaplan and Francis, the most popular type. Pelton turbines are not used at Belo Monte, the other two are. Since 97.9% of the dam's power capacity is generated from Francis turbines, and since these are by far the most popular type of dam technology internationally, the majority of this section will focus on Francis Turbines.

History

James B. Francis developed Francis Turbines in mid-19th century Massachusetts[1]. Francis developed the turbine due to the inefficiencies in waterwheels, which were the previous most popular model of turbines. However, such wheels suffered from backwater, which prevented them from turning effectively. Francis' innovation was to create a waterwheel turning horizontally, as seen in Figure 3.2. The Francis turbine quickly became the most popular turbine for dams due to both its efficiency and the fact

that the perpendicular arrangement between the turbine itself and the rotating vertical shaft protected the generator from water, diminishing the likelihood of water damage to the generator[li].

In 1913, Austrian professor Viktor Kaplan invented the Kaplan turbine. The design for the Kaplan turbine was inspired by that of the Francis turbine[lii], and it aimed to solve some of the inefficiencies of the Francis turbine, namely that it required a high hydraulic head to function. By combining adjustable blades, Kaplan was able to alter the pressure of the water, negating the need for a high head (though, with Kaplan turbines, a very low head causes significant drops in efficiency). Like the Francis turbine, the Kaplan turbine requires a high flow of water[liii]. The other innovation of the Kaplan turbine was to alter the shape of the turbine such that water would enter from above, axially, rather than radially as in the case of the Francis turbine (as seen in Figure 3.2 and 3.4). Consequently, Kaplan turbines are able to create their own pressure differential, rather than relying on naturally occurring or man-made high heads[3]. The Kaplan turbine is generally expensive to install and design, more efficient than the Francis turbine, and has a lower overall hypothetical power generation capacity. Often, where possible, the two are used in conjunction. This is the case at Belo Monte.

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[3] A hydraulic head is the difference in height between the surface of the reservoir from which water enters the turbines, and the river in to which water exits after turning the turbines.

Turbine Efficiency

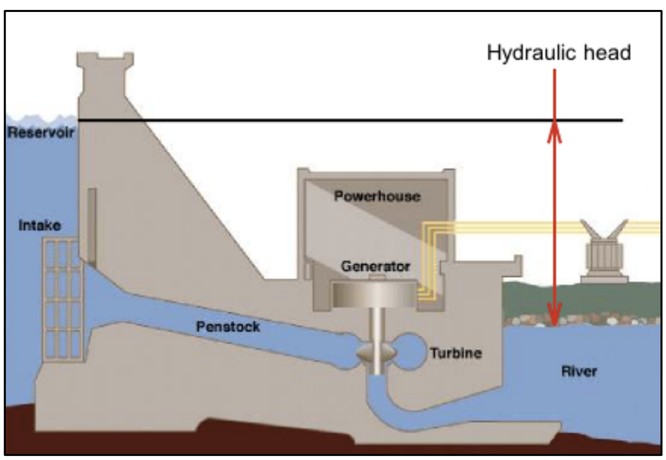
Within this section and throughout the paper, we have made references to the efficiency of the turbines. The efficiency of a turbine is taken to be the proportion of kinetic energy (of the water) that transfers to mechanical energy (the spinning of the turbine), which in turn transfers to electrical energy, and is then distributed to the grid[liv]. The key determinant of efficiency, then, is the proportion of mechanical energy that is not turned into electrical energy, and is "lost". Some may be lost due to the friction of the turning of the turbine blades and some mechanical energy may be dissipated as heat energy or sound energy. Fortunately, both the Kaplan and Francis turbines are extremely efficient when compared to steam or wind turbines. The Francis turbine is approximately 90% efficient, and much of this is down to the fact that each turbine (Francis, Kaplan or Pelton) is designed specifically with the site's specifications in mind (water flow, head and so on). The Kaplan turbine is generally around 92% efficient. The difference is down to the fact that the axial entry (discussed below) of the water in the Kaplan turbine reduces loss of energy due to friction, as compared to the Francis turbine, which loses more energy due to blade friction since water hits the blades radially.

Design

Two major determinants of the power generating capacity of a dam are the hydraulic head, as seen in Figure 3.1, and the flow rate, which is the velocity with which the water travels through the penstock and hits the turbine, also seen in Figure 3.1. Pelton turbines

require large hydraulic heads and low flow rates and are built in mountainous regions, while Kaplan turbines require low water heads and high flow rates, and are built in low lands, such as around the Pimental section of the dam. Francis turbines can be used in areas of high hydraulic heads and high flow rates, which allows for greater power generation capacities than the other two designs. The major downside to such a design specification is the significant shift in landscape required by the turbines; this is why Belo Monte requires a large reservoir; the area does not have a naturally occurring high hydraulic head (an example of a naturally occurring high water head is a waterfall). However, if the area was not dammed, and only Kaplan turbines were used for the full 11,233MW capacity, 446 turbines, as opposed to the current 27, would be required

Figure 3.1[lv] : Hydraulic Head



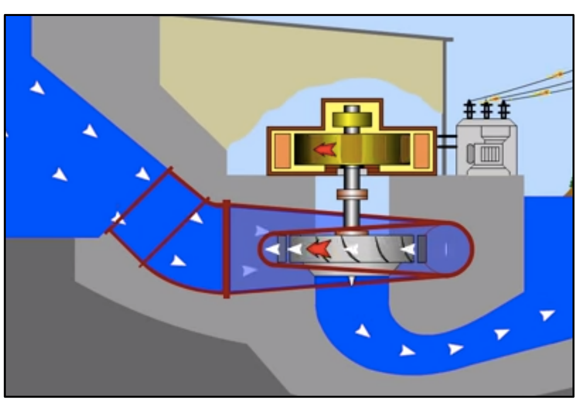
There is a second distinct benefit to using Francis generators, and that is the fact that the dam can be used for pumped storage. This reuses the same water more than once by keeping water in reserve for when demand for electricity peaks. During hours of low demand, the blades of the Francis turbine reverse in their direction of rotation, pushing

additional water back in to the reservoir. At peak times, this accrued water is allowed to flow back through the turbine-generators, satisfying the increased demand at hours of the day, and preventing over-generation in non-peak hours. In effect the dam can act like a battery, rapidly scaling up and scaling down production of power as required.

With this in mind, Francis turbines operate in areas with hydraulic heads of between 10 and 600 meters. The Francis turbines of Belo Monte have an average hydraulic head of 89.3 meters, which, even with the large drop of the "Big Bend," is only possible in this section of the Amazon due to the significant damming and the creation of the reservoir. By contrast, the Kaplan turbines at Pimental have an average hydraulic head of 13.1 meters. This significant difference points to the greater need for building the reservoir to allow for the use of the Francis turbines.

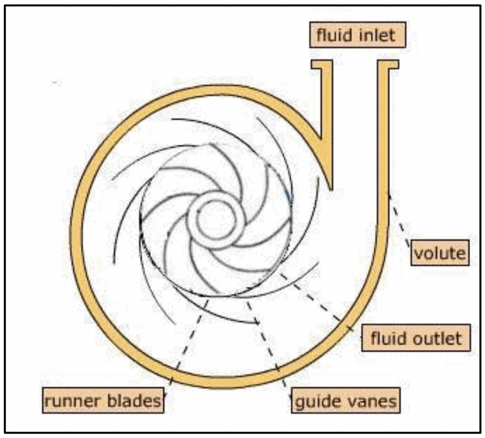
In Figure 3.2 we see that water hits the Francis turbine radially and turns turbine horizontally as it enters the blades. This, in turn, rotates the vertical shaft, which rotates inside an electrical generator. Figure 3.3 reveals an above view of the turbine, and shows

Figure 3.2[lvi]: Francis Turbine



how the blades catch the water as it enters via the penstock. The Belo Monte Francis turbines have a diameter of 11.2 meters, and each turbine weighs approximately 320 tons[lvii]. As Francis had originally determined, the horizontal rotation of the blade prevents backwater, which would reduce the efficiency of the turbine, as in vertical rotation.

Figure 3.3[lviii]: Francis Turbine Overhead View

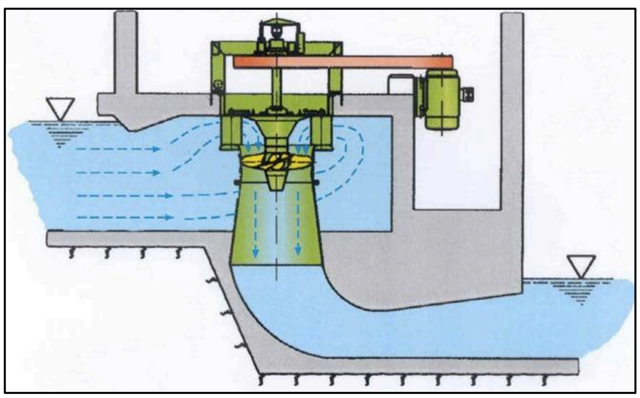


The spinning of blades rotates the vertical shaft. These shafts can typically rotate at between 80-1000 rounds per minute; the Belo Monte Francis turbines operate at 90rpm[lix]. As the shaft rotates inside the generator, electricity is produced, which is transformed into high voltage, to be transmitted across the country via the grid.

Kaplan Turbines

Kaplan turbines are much smaller than Francis turbines, and were developed in 1913 as an extension of the Francis turbine. As mentioned, the Kaplan turbines at Belo Monte have a generating capacity of only 25.9MW. The major benefit they present over Francis turbines is that they are able to generate electricity efficiently in situations of low heads. Kaplan turbines also have adjustable blades that allow water pressure to change as water rotates through the turbine.

Figure 3.4: Kaplan Turbine



This, combined with the shape of the turbine (pictured in Figure 4.3) has two effects. The first is, as mentioned, that a large hydraulic head is unnecessary. The second is that it is more efficient than the Francis turbine. Despite being more efficient, however, Kaplan turbines' maximum power generation lags well behind the Francis turbine for several reasons. First, the water velocity as it hits the turbine is far less than Francis turbines, due to the lower hydraulic head. This gives a resulting expected rpm between 79 and 429. Second, a lower volume of water is pumped around the blades, because the chamber itself

is smaller than its Francis equivalent. Kaplan turbines are also more expensive to design and install per unit of output than Francis turbines, because the water enters axially in, and axially out, whereas the Francis turbine has water entering radially and leaving axially. Additionally, unlike Francis turbines, Kaplan turbines cannot be used to provide pumped storage. In the case of Belo Monte when there is expected variation of demand of power over a day, this is a significant disadvantage.

IV. COST-BENEFIT INPUTS

In this section, we consider the relevant costs and benefits that will allow us to determine the net present value of the dam, and thus allow us to judge the project. Our cost-benefit analysis of the dam consists of three main sections: financial and economic costs and benefits, social costs and benefits, and environmental costs and benefits. Figures calculated throughout the "Cost-Benefit Input" section are either one-off costs or yearly costs (for a year in which the dam is at full operational capacity). The projection and discounting of costs occurs in Section IV.

Financial and Economic Costs and Benefits

The financial and economic costs and benefits of the project primarily consist of the cost of construction and the value of the electricity produced by the dam over its lifetime. Other considerations include the losses in fishing and ornamental fish collection, the opportunity cost of the dam (represented by the cost of supplying an equivalent amount of energy through alternative energy sources), and the operational costs of the dam.

Construction and Financing Costs

The cost of the Belo Monte Dam is a highly contentious issue, with estimates ranging from $13 billion to $27 billion[lx]. We decided to use a recent study at Oxford's Said School of Business to estimate our own cost of the Belo Monte Dam, using the initially

proposed and final figures for Brazil's other major dam, Itaipu, to help direct our calculation. The Said School of Business study compared the estimated and true costs of a sample of 245 "mega-dams" built between 1934 and 2007 in order to calculate mean overrun cost values for major dam projects. The study arrives at a mean overrun cost value of 2. This means that final costs were, on average, double the initial cost estimate. The median overrun cost value was 1.27. To check if the mean figure could reasonably be applied to Belo Monte, we compared it to the overrun cost value of Itaipu, the only dam in Brazil comparable to Belo Monte. We found that Itaipu had an overrun cost value of 2.4. Therefore, we believe it is reasonable to apply an overrun factor of 2 to Belo Monte, despite this figure being significantly larger than the median. We will scale this overrun factor in the scenario analysis (Section V) to produce different scenarios..

Table 4.1: Estimating the Final Cost of Belo Monte

Projected Cost	$11.3 billion
Mean Overrun Cost Value	2.0
Estimated Final Cost	**$22.6 billion**

The initial projected cost of the dam, according to Norte Energia, was R$29 billion when it bid for the project in 2010[lxi]. Thus, using the cost overrun value of 2, we will state that the estimated final cost of the dam is R$58 billion. Converting these values into US dollars, we reach the numbers presented in Table 4.1. To be clear, these costs include the materials needed to build the dam, wages paid to the approximately 25,000 workers that built the dam, the housing for these workers, several injections of funds into the local

economy, necessary transmission lines and roads, and the present value of the interest payments needed to pay off debts incurred when financing the dam.

Operation Costs

Another key economic and financial cost is the operation of the dam. Though figures related to the operation of the dam are not yet published, we predict that the number of workers needed to operate the dam once it is at full capacity to be equal to 2,674. We found this number by considering Brazil's two other major dams – we looked at how many workers they had relative to their installed capacity, took the average of that ratio, and applied it to Belo Monte. Table 4.2 shows the results.

Table 4.2: Projecting Number of Workers

	Belo Monte	Itaipu[lxii]	Tucuria[lxiii]
Workers (to build)	**25,000**	40,000	20,000
Installed Capacity (MW)	**11,233**	14,000	8,370
Workers (to operate)	**2,674**	3,153	2,100

Knowing that the average wage of workers at Itaipu comes to about $583.66 per month, we will assume that the same holds true for Belo Monte[lxiv]. Therefore, over an entire year, the cost to Norte Energia from paying their workers will amount to around $18.73 million.

Table 4.3: Cost of Operation

Workers (to operate)	2,674
Average Wage of Workers	$583.66 (per month)
Annual Costs of Operation	**$18.73 million**

Of course, there may be other costs associated with operating a dam, and we have excluded the issue of maintenance – for instance, you may have to repair or replace turbines if it happens to be faulty – but, since we do not have the information required to accurately predict or quantify these other costs, and since they would be largely negligible in the scheme of the overall cost-benefit analysis, these have been excluded from the calculation.

Cost of Losses in Fishing and Ornamental Fish Collection

Belo Monte has other economic costs that are distinct from construction costs. Of the estimated 20,000 people being displaced by Belo Monte, many derive their income from fishing and the collection of ornamental fish, i.e. fish that are used in aquariums. Residents of the affected area have historically caught an average of 464,000 kilograms of fish per year[lxv]. To determine an average market price, we used the revenue generated from fishing exports divided by the number of kilograms exported in 2010, the last year with available data. This price was computed to be $6.89/kg[lxvi]. Data on ornamental fish collection, meanwhile, points to an average of 321,600 ornamental fish collected per year at an average price per fish of $2.45[lxvii]. Using these values, we determined the annual

loss in income as a result of decreased fishing and ornamental fish collection to be $3,984,880. A breakdown of this figure is presented in Table 4.4.

Table 4.4: Annual Cost of Fish Related Losses

Annual Cost of Losses in Fishing	**$3,196,960**
Annual Cost of Loss in Ornamental Fish Collection	**$787,920**

Energy Revenue Benefit

The major benefit of the Belo Monte dam is the generation of electricity. Belo Monte's annual revenues depend on the price per megawatt hour Norte Energia receives and the number of megawatt hours of energy the dam generates. It is important to use the price of electricity that Norte Energia receives as opposed to the price of electricity on the market because the market price of electricity reflects all types of energy generation and is often subject to taxes and subsidies[lxviii]. During the bidding process for the dam project, the Brazilian government set a price ceiling of $32.3/MWh (R$83). Norte Energia won the bid with a price of $30.34/MWh (R$77.97). Interestingly, and as briefly mentioned in the "History" section, Odebrecht, Camargo Correa, and CPFL, all large Brazilian construction companies, dropped out of the bidding process[lxix]. They claimed that the price ceiling set by the government was too low, and feared that the project would not generate sufficient returns. Recall from Section I that Belo Monte is projected to produce 39,493,440 MWh annually. The calculation of the net present value of energy revenue is undergone in Section IV. Relevant figures are presented in Table 4.6.

Pricing Benefit Relative to Other Energy Sources

We assume that Brazil would meet its demand for energy regardless of whether Belo Monte was being built. Therefore, we wanted to determine if it was cheaper for Belo Monte to generate energy relative to other methods of generation purely on a price per MWh basis. Belo Monte is estimated to produce 39,493,440 MWh annually and Norte Energia won the contract to produce power at $30.34/MWh. We obtained contracted prices per MWh for other methods of energy generation and created a weighted average alternative energy price. Weights for each energy source were determined by Brazil's current energy distribution. As previously mentioned, 20% of Brazil's energy is not generated from hydroelectric power. This twenty percent is made up of other renewables (biomass, wind, and solar), fossil fuels, and nuclear. Prices and weights (scaling from the 20% to 100%) are found in Table 4.5.

Table 4.5: Weights and Prices of Alternative Sources

Source	**Weight**	**R$/MWh**	**$/MWh**
Biomass[lxx]	15%	58	23
Wind[lxxi]	10%	189	74
Solar[lxxii]	5%	215	84
Fossil Fuels[lxxiii]	55%	205	80
Nuclear[lxxiv]	15%	193	75

Average	**$70.09/MWh**

Table 4.6: Belo Monte vs. Alternative Sources

	Belo Monte	Alternative Sources
$/MWh	30.34	70.09
MWh per year	39,493,440	39,493,440
Total cost per year	1,198,230,967	2,768,198,169

Savings per year	$1,569,967,200

We computed the average alternative energy price to be roughly $70.09/MWh. This is almost $40/MWh above Belo Monte's contracted price. Using this figure, we calculated the amount Belo Monte would save each year as a result of not producing energy using other sources (this figure is for a year where Belo Monte is fully operational).

<u>Unquantifiable Financial and Economic Cost and Benefits</u>

Belo Monte will inevitably have economic benefits that are difficult to quantify. The increase in installed capacity will allow Brazil's economy to continue growing. The electricity generated from Belo Monte will help meet consumer demand as more citizens move out of poverty and consume more electricity. This benefit to people is difficult to quantify since the value they derive from having stable, cheap electricity may well be greater than the price they actually pay for the electricity, assuming such electricity can be reliably provided. Additionally, the knock-on effect to industry is similar. Much of the benefit to the rest of the country is in terms of what the increased power capacity allows

power-using industries to do. For instance, it might allow firms to build additional factories, in the knowledge that they now have access to the power required to run such factories, thus increasing the output potential of the country. An example of this is the expected boost in mining due to Belo Monte, such as the Canadian company Belo Sun Mining Corp, which is in the process of opening a gold mine in the area[lxxv]. This might complicate socio-economic and environmental factors, but also might likely add to the value of national GDP. The net effect going forward is unclear since we do not know, for example, how much such a mine will end up costing or how many local workers versus imported workers the Canadian company will hire.

Another unquantifiable cost of the dam is the legal battles regarding construction, which have been ubiquitous since the dam has been proposed, as covered in the introduction. The legal fees, and the time spent engaging in legal disputes, are significant, but data is either not readily available, or ambiguous. These legal battles are not costless, but they are not included in the construction costs for the dam either. As such, this greater expenditure on the dam is an area to consider when evaluating whether it is cost effective. It is not, however, straightforward to assign values to this and so we are left to consider the true value of legal costs.

Finally, as briefly mentioned in "Operation Costs," maintenance may be a significant cost over the lifetime of the dam. Turbine failures or general wear and tear lead to replacement and repairing costs. Though not easily quantifiable, these costs must also be noted.

Environmental Costs and Benefits

The environmental costs and benefits of the dam are varied. On the one hand, as renewable sources of energy, dams such as Belo Monte have a positive effect on the environment because they produce energy with a smaller carbon footprint when compared to substitutes such as oil. On the other hand, the construction of the dam involves an enormous diversion of water, which will lead to the flooding of approximately 500km². This leads to both losses in carbon absorption and the release of methane and carbon dioxide, as the flooded trees anaerobically decompose. However, since approximately 50% of this land was already deforested during the construction of the Trans-Amazonian Highway, we use the figure 250km² during our calculations[lxxvi].

Though the above considerations will be quantified, there are also environment costs and benefits to the dam that are difficult to quantify. These include, for example, losses in biodiversity and animal life. We discuss these costs and benefits further at the end of this section, in "Unquantifiable Environmental Costs and Benefits."

Positive Carbon Footprint

The most obvious environmental benefit of the Belo Monte Dam is the reduction in CO_2 emissions that will result from producing energy from a renewable source. When building our counterfactual argument, we assume that oil would replace hydroelectric as a source of energy. We decided to choose oil as our counterfactual due to the ease with

which Brazil would be able to scale their oil consumption. Moreover, the assumption that oil would be a substitute for hydroelectricity is common practice when assessing the environmental impact of dams. Again, note that, although there is a CO_2 reduction from the switch in energy sources, the overall impact of the Belo Monte Dam in terms of CO_2 is ambiguous, as construction, deforestation, and flooding all have associated CO_2 costs.

Table 4.7: Oil vs. Hydroelectricity

Barrel of Oils Equivalent to an Hour of Operation	2,689.8[4]
Metric Tons of CO_2 Saved per Hour of Operation	1,156.6[5]
Metric Tons of CO_2 Saved a Year	**9,994,861**[6]

As Table 4.7 shows, if oil were used to produce the same amount of energy that Belo Monte will supply, Brazil would emit an extra 9,987,840 metric tons of CO_2 per year. In other words, on average and given our assumptions, every hour of electricity production at Belo Monte prevents the emission of 1,156.6 metric tons of CO_2.

[4] Belo Monte's average power production = 4,571 MW. Translate into kWh: 4,571*(1,000) *1 = 4,571,100 kWh. 1 Barrel of Oil Equivalent = 1,699.4 kWh. So, 4,571,000/1,699.4 = 2,689.8 Barrel of Oil Equivalent.
[5] To find the CO_2 emissions of a barrel of crude oil, we multiply the heat content of the barrel by its carbon coefficient, the fraction oxidized, and the molecular weight of CO_2 relative to carbon. Therefore, (5.8 mmbtu/boe)(20.31 kg C/mmbtu)(44 kg CO_2 / 12 kg C)(1 metric ton/1,000 kg) = 0.43 metric tons CO_2/barrel, and 2,689.8 *0.43 = 1,156.6 metric tons of CO_2. http://www.epa.gov/cleanenergy/energy-resources/refs.html
[6] From per hour to per year, we just multiply 1,156.6*(24*360) = 9,994,861 metric tons of CO_2.

Negative Carbon Footprint

This section will analyze the extent to which the two main negative environmental impacts we quantify act against the positive carbon footprint. First, we will consider the loss in carbon dioxide absorption that occurs due to the flooding of the land. Second, we will quantify the release of greenhouse gases due to flooding. Together, these two effects act against the positive carbon footprint. However, we determine that it is a fairly negligible counteraction.

Losses in Carbon Dioxide Absorption

The losses in carbon dioxide absorption essentially represent a type of environmental opportunity cost of the land flooded by the reservoir. When the land is flooded, the trees that previously occupied that land do not photosynthesize and absorb carbon dioxide anymore, and hence the positive carbon footprint they normally create is nullified.

Since the approximately 5,500,000 km^2-large Amazon absorbs an estimated 1.7 billion metric tons of CO_2 a year, we can easily calculate the amount of CO_2 that is not absorbed every year as a result of the dam being built[lxxvii]. Table 4.8 presents the key figures.

Figure 4.8: Negative Carbon Footprint from Lack of CO_2 Absorption

% of Amazon Covered by 250km^2	0.0045%[7]
Metric Tons of CO_2 Not Absorbed per Year	**77,272.6**[8]

[7] 250 km^2/5,500,000 km^2 = 0.000045.
[8] 1,700,000,000 metric tons of CO_2 a year * 0.000045 = 77,272.6.

Greenhouse Gases Released by Underwater Trees

As water floods an area of trees, it does more than just prevent the trees from absorbing CO_2 and inhibit the ability of the Amazon to act as a carbon dioxide sink. The flooding also causes the plant life to release the large amounts of carbon dioxide and methane (CH_4) already tied up in them in the form of glucose as they decompose. This underwater, anaerobic decomposition follows the equation:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Thus, we see that for every molecule of glucose decomposed, three carbon dioxide molecules and three methane molecules are released. There are approximately 20 kg of carbon in every square meter of a dense rainforest such as the Amazon, and it is estimated that methane has a global warming potential that is roughly 21 times that of CO_2 (that is to say, methane is roughly 21 times better at trapping heat in our atmosphere than carbon dioxide)[lxxviii]. Using the chemical equation and the two aforementioned facts, we can calculate the metric tons of CO_2 emitted by the decomposing trees.

As Table 4.9 shows, the carbon dioxide and methane released by the decomposition of the flooded trees is equivalent to 55 million metric tons of carbon dioxide. For the purpose of this paper, we take this to be a one-time event. In reality, the season nature of the water flows in the Xingu River will result in the reservoir contracting and expanding over time, which, in turn, leads to plants encroaching onto the banks of the reservoir and then being flooded again when the reservoir expands. However, due to the high uncertainty of projecting this seasonal growth in plant life and the miniscule amount of

carbon dioxide and methane these plants would release relative to the initial emission of 55 million metric tons, this consideration has not been quantified.

Table 4.9: Negative Carbon Footprint from Decomposition

Metric Tons of Carbon in 250km^2	5,000,000[9]
Metric Tons of CO_2 Released	2,500,000[10]
Metric Tons of Methane Released	2,500,000
Total Metric Tons of CO_2 Released (assuming 1 ton of CH_4 = 21 tons of Methane)	**55,000,000**[11]

Monetary Value of CO_2 Emissions

What remains is to find a monetary value for these savings in and costs of CO_2 emissions. The social cost of CO_2 is a topic of some controversy, and it is difficult to pin down an accurate number. For instance, the European Union's Emission Trading Scheme has seen the price of a metric ton of carbon dioxide fluctuate from as low as €0.10 to a peak of about €30 ($0.12 to $36.86 at €1.23/$1)[lxxix]. Other calculations have estimated the net damage carbon dioxide imposes on society and divided that by the carbon dioxide emitted, finding a price of carbon dioxide of $25[lxxx]. A series of White House technical support documents in 2010 calculated a social cost of carbon range from $7 to $81[lxxxi].

[9] 20 kg C/m2 * 1,000,000 m2/km2 * 250 km2 * 1 metric ton/1,000 kg= 2,500.
[10] According to the chemical reaction of glucose breaking down into carbon dioxide and methane, we saw that carbon is equally split between the two greenhouse gasses, so 5,000,000/2 = 2,500,000.
[11] (2,500,000) + 21*(2,500,000) = 55,000,000.

For our paper, we chose to use a social cost of carbon of $25. This is the figure found in a Swiss Federal Institute of Technology Zurich paper that estimated the cost using damages over carbon dioxide emissions. This price is also very close to the median value of $24 found by a paper published in the March 2014 “Nature Climate Change” journal that compared and contrasted a multitude of different social costs of carbon dioxide[lxxxii].

Although we have now established an initial social cost of carbon dioxide per metric ton, there is one other crucial consideration: as the world suffers more and more from the effects of climate change, the social cost of carbon dioxide per metric ton should increase. To find the annual increase in price, we used a 2013 White House study that attempts to calculate the social cost of carbon under a variety of different scenarios. We took these projections, and from them calculated the average annual growth rate in the social cost of carbon dioxide, which we found to be 1.95%[lxxxiii]. Thus, Table 4.11 displays the social cost of carbon dioxide per metric ton when using the cost of $25 and an annual price increase of 1.95%.

Now, with a social cost of carbon and the annual positive and negative carbon footprints of the dam, as well as the one-off costs associated with the emission of carbon and dioxide and methane when the plant life decomposes, we will be able to calculate the net environmental effect of the dam, which we leave for Section IV. Table 4.10 below does, however, exhibit the net effect associated with the first year of full power production of the dam (2019), along with the total cost of the carbon dioxide and methane emissions

that occur due to anaerobic decomposition (any consideration of discount rates is left for section IV). For the total cost from decomposition, it is assumed that decomposition starts the first year of electricity production, 2015, and is completed after five years – the amount of carbon dioxide and methane emitted is further assumed to be equal year-to-year.

Table 4.10: Annual Net Environmental Effect and Decomposition Cost

	Value
Annual Positive Environmental Effect	$269,771,558
Annual Negative Environmental Effect	$2,254,486
Net Environmental Effect	**$267,517,072**
Total Cost from Decomposition	**$1,429,667,670**

Figure 4.11: Projected Social Cost of Carbon

Year	Price ($)
2015	25.00
2016	25.49
2017	25.98
2018	26.49
2019	27.01
2020	27.53
2021	28.07
2022	28.62
2023	29.18
2024	29.74
2025	30.32
2026	30.92
2027	31.52
2028	32.13
2029	32.76
2030	33.40
2031	34.05
2032	34.71
2033	35.39
2034	36.08
2035	36.78
2036	37.50
2037	38.23
2038	38.98
2039	39.74
2040	40.51
2041	41.30
2042	42.11
2043	42.93
2044	43.76
2045	44.62
2046	45.49
2047	46.37
2048	47.28
2049	48.20
2050	49.14
2051	50.10
2052	51.07
2053	52.07
2054	53.08

Unquantifiable Environmental Costs

One environmental consideration and cost is the decrease in animal and plant life and diversity associated with the dam. A few species that will be particularly affected by Belo Monte are the yellow-spotted river turtle, white-cheeked spider monkey, plant-eating piranha, Xingu poison dart frog, and the zebra pleco fish[lxxxiv]. These species do not have a monetary cost associated with them per se. They are not generally captured for zoos, nor are they sold in markets for food, and thus there is no real market value that can be attached to them. This does not mean, however, that they are not a loss, and a significant one as a result of the building of the dam. The value of the diversity of life on the planet is more than just the sum of money that could be expended attempting to save it, or the money that could be made by selling it. The intangible value that many place on biodiversity should not to be underestimated. As pressure for climate change deals between governments gather pace, and as these deals actually occur, this presents us with real examples of the manifestation of the value people and their governments place on protecting biodiversity.

Our reliance on using the resources of biodiversity in places such as the Amazon is indisputable. The derivation of medicines, in particular, has relied heavily on the Amazon, and it is estimated that less than 1% of flowering species have been studied for their potential medicinal value[lxxxv]. Furthermore, the scientific value of the region, and the contribution it could make to our understanding of evolution and various responses of animal species to an array of evolutionary pressures. Nor can we rule out unexpected

implications of such research. For instance, presently, research is being conducted on electric eels in South America which are able to use electric shocks to activate the neurons of prey, essentially controlling their movement. It is hoped that such research in the future could be useful in repairing brain damage or other neurological diseases[lxxxvi]. The loss of such diversity might well signify the loss of potential avenues of research that could result in tangible benefits to society in the future, and whilst difficult to assign a monetary value to such hypothetical, it does merit further consideration.

We have already quantified the impact on the ability of the Amazon to capture carbon dioxide as a result of the loss of this area of rainforest. Something that is much more difficult to predict, however, is the impact on climate sensitivity, which is defined as the equilibrium temperature change in response to changes in radiative forcings. Forcings are taken to be the difference between the amount of sunlight that is absorbed by Earth versus that which is radiated back in to space. The impact of this is not linear, as factors such as water vapor feedback, cloud feedback and albedo feedback can all intensify the effect on the atmosphere[lxxxvii]. Here, the albedo affect might be relevant. Albedo is defined as the reflective power of a surface. Previously, the area being flooded by the dam was forest, with much less reflective power than a still reservoir of water. This could impact the local cooling of the area, which in turn might affect the probability of drought[lxxxviii].

Social and Political Cost-Benefit Analysis

The final major category of cost and benefit inputs that we consider is social and political. Unfortunately, these are very difficult to quantify, as they vary from severed ties between the Brazilian executive branch and the National Indian Foundation of Brazil (FUNAI) to potential for political unrest. One type of social cost that can be quantified, however, is the displacement of people due to the construction of Belo Monte.

Displacement Costs

The construction of the Belo Monte Hydroelectric Dam Complex, and specifically the Canals Reservoir created for the main powerhouse, has displaced approximately 30,000 people from their homes along the Xingu River. We choose the number 30,000 because there are consistently two figures that appear in news reports and papers when discussing the number of people displaced by Belo Monte's construction: 20,000 and 40,000[lxxxix,xc]. Since we have little reason to believe that one number is truer than the other, and since these numbers appear with roughly the same frequency, we have decided to split the difference and assume that 30,000 people will be displaced.

In order to quantify the effect of displacement, we decided to follow the trend most commonly used when assessing hydroelectric dams; that is, costs of displacement are equated to the costs of building new homes. Luckily, there is a prominent Brazilian government program called "Minha Casa, Minha Vida" (My House, My Life) that

provides homes to low-income families such as those affected by the dams. The cost of an average house built by "Minha Casa, Minha Vida" should thus fairly accurately predict the cost of displacement. The program has spent $13.23 billion to build one million homes, for an average price of $13,230 per home[xci].

Two other facts allow us to calculate the total costs of displacement. First, the average household size in Brazil is 3.3[xcii]. Second, we know that the construction of 8,000 homes has already been included in Norte Energia's initial budget[xciii]. We consider social costs of displacement to thus be equal to the number of homes that have not been built to support displaced families. In other words, displaced families with no constructed home "suffer" at a cost equal to the construction cost of the home they are missing (alternatively, if Norte Energia does build the necessary additional homes, our calculated figure will be the amount they need to spend). Table 4.12 presents the total costs of displacement.

Table 4.12: Total Costs of Displacement

# of Displaced Families Without a Home	1,091[12]
Cost of a Family Home	$13,230[13]
Total Costs of Displacement	$14,432,727[14]

[12] 30,000 families displaced/3.3 people in average family – 8,000 families with homes already built for them = 1,091 families.
[13] R$34 billion/1 million homes/(R$2.57/$) = $13,230
[14] $13,230*1,091 = $14,432,727.

Therefore, we see that the total costs of displacement amount to $14,432,727. Surprisingly, this is actually quite a small figure – it is less than Belo Monte's annual cost of operation (calculating in "Operation"). However, there are, of course, many other costs of displacement that are not sufficiently captured by our calculation. These include severed community ties and possible tensions caused by an influx of families into a new area.

Unquantifiable Social and Political Costs and Benefits

One major potential political benefit is continued and even increased energy security. The International Energy Agency defines this as "the uninterrupted availability of energy sources at an affordable price"[xciv]. Certainly one goal of Belo Monte is to provide energy at an affordable price. We cannot be certain if there will be uninterrupted availability of energy, however, as the 2001 Brazilian Drought showed[xcv]. Energy security can also be considered in terms of the relationship between other nations around the world, and the potential dangers present in relying on importing types of energy from other nations. There are several implications of energy security.

For one, building internal capacity for power generation, rather than importing energy resources from abroad, means that Brazil is not dependent on fluctuations in the supply of energy from other nations. Thus, it is more able to insulate itself from, for example, regional instability in the Middle East, from which it might import oil. Energy security means that Brazil can, in most instances, exert control over how and when it produces

power. In other words, higher energy imports makes Brazil less vulnerable to international crises that would precipitate a fall in energy availability. Clearly, energy independence is difficult to quantify, but what we do know is that insulating oneself from international fluctuations in, say, the price of oil, would be good for the stability of energy pricing. This does, however, assume that the domestic substitute is able to perform as expected year-round. The worst case for Brazil would be one in which their attempt to insulate themselves from international fluctuations in energy (the dam) fails to work as planned, and they are forced to import energy from abroad despite already spending a considerable sum on a dam.

One significant cost the government may face is a lack of trust if the results of Belo Monte do not turn out according to plan. This is due to both the exorbitant cost of the dam and the potential problems it will face in terms of supplying power reliably due to seasonal variation in rain and water supply. The least the Brazilian public will expect from such an expensive undertaking is reliable energy, and yet variable rainfall, the risk of drought, and the risk in general of the dam underperforming puts this expected output at risk. This could have a significant political cost for the government, as an inability to provide basic goods and services worsens along with confidence in the government. The result could be anything from unfavorable election results to protests and civil disobedience. Ultimately the credibility of the government on the domestic scale will affect Brazil's ability to be an international power with influence. Any loss of credibility domestically will impact Brazil's ability to project power abroad, compromising its goals in bodies such as the G20, or the United Nations. This is unquantifiable but could lead to

increased geopolitical uncertainty, and potential economic costs down the road in the form of less favorable treaties or influence in relevant negotiations. A related cost is also the integrity of legal and democratic institutions in Brazil. As detailed in the introduction, the political machinations that occurred in terms of firing civil servants unwilling to sign off on the dam works to undermine the faith that Brazilian citizens have in the ability of such institutions to protect them. Compromising the ability of government bodies such as IBAMA may pay off for the Brazilian government now, but in the future an acquiescent energy department may be a catalyst for poor decisions.

A further cost might be increased tensions in local cities as displaced peoples are moved to already occupied, resource-constrained areas. The effect could be reminiscent of the rural to urban migration that, at least in part, caused destabilizing slums such as Rocinha, in Rio de Janeiro. Even though Norte Energia and the government are setting aside resources for those displaced, if this proves to be insufficient, as our predictions suggest, the destabilizing influence of forced migration, especially in Altamira, Belo Monte's neighboring city, could be significant. Moreover, issues such as ethnic tensions may further compound displacement, given that many of the displaced peoples are Indigenous. Furthermore, the large boost in the labor force supply may not be met with an increase in jobs, and thus the stress of the infrastructure of the city from unemployed people could be significant.

V. ANALYSIS

In this section, we use the numbers from Section IV as inputs in a series of scenarios that might occur over the lifetime of the Belo Monte Hydroelectric Dam Complex. The numbers calculated in Section IV were always either one-time costs or benefits or annual costs or benefits (for years when the dam is fully operational). This section projects these costs and benefits, discounts them, applies a number of assumptions, as well as explains the process we used to calculate our final net present values (NPVs).

Crucially, we analyze the decision to build Belo Monte from a 2011 vantage point. That is to say, we take the perspective of a benevolent social planner who, in 2011, just prior to the ground being broken at Belo Monte, calculates the NPV of the project.

We also need to define two key time periods: the construction period, and the ramping up period. The construction period is simply the number of years between when construction begins and when construction ends (which we take as the first year in which the dam is fully operational, i.e. the year it first reaches its full installed capacity of 11,233 MW). The ramping up period, meanwhile, is the time period that begins with the year the dam starts producing electricity and ends with, again, the year during which the dam first becomes fully operational. Therefore, the ramping up period is a subset of the construction period.

We will use the same discount rate for every scenario (though after our discussion of all seven scenarios, we will conduct a discount rate sensitivity analysis). The discount rate we have chosen is 12%. Discount rates for energy projects are not generally derived from yields on government bonds[xcvi]. However, this argument generally refers to the United States. It is argued that this rate is "riskless" and purely a financial rate, not reflecting the real opportunity cost of investing in government bonds. That is to say, investors could put that capital to use in other ways. However, Brazilian government bonds should not be considered riskless. In March of 2014, Standard & Poor's dropped Brazil's credit rating to BBB-[xcvii]. This is the lowest credit rating for debt to be considered investment grade. Riskless government debt in the United States has a credit rating of AAA, the highest rating possible. The initial feasibility study conducted by Norte Energia in 2002 used a discount rate of 12%[xcviii]. This is in line with yields on Brazilian government debt, which currently stand around 12%. Moreover, a discount rate of 12% is appropriate because Norte Energia is 90% government-owned and, as a result, possible burdens of deficits from the dam will fall on the taxpayers[xcix].

There are several more assumptions that hold true for all scenarios we calculate:

- The time horizon (lifetime of the dam) is 50 years (starting from 2011, the beginning of construction).
- Belo Monte starts producing electricity in 2015.
- The following scale up during the ramping up period:
    - Energy revenue benefits (scales up by even increments).
    - Pricing benefit relative to other energy sources (scales up by even increments).
    - Positive carbon footprint (metric tons of CO_2 scale evenly, but dollar values do not due to increasing CO_2 prices).
- Construction costs are divided evenly across the construction period.
- Operational costs are first incurred once construction is complete and are incurred annually for the rest of the time horizon.
- The annual cost of losses in fishing is constant across the 50-year time horizon.
- The annual cost of losses in ornamental fish collection is constant across the 50-year time horizon.
- The negative carbon footprint from decomposition (and the subsequent release of CO_2 and CH_4) is split evenly across the years 2015-2019.
- The negative carbon footprint from foregone CO_2 absorption starts in 2015.
- Displacement costs are divided evenly across the construction period.

Scenario A: Base Case Scenario

Our Base Case scenario is the one created using all the numbers in Section IV. We also use the dates from the "Brief History" section of Section II. That is, the construction period to is 9 years (2011-2019) and the ramping up period is 5 years (2015-2019)

To reiterate, Table 5.1 exhibits the inputs for the base case scenario:

Table 5.1: Inputs

Discount rate	12%
General	
Installed capacity	11,233
% of capacity used	40.70%
Reservoir Area m^2	500,000,000
Years of construction	9
Years ramping up	5
Economic	
Initial budget	11,300,000,000
Overrun factor	2.00
Number of operational workers	2,674
Yearly wage	7,004
Contracted price per MWh	30.34
Alternative source price per MWh	70.09

Market price of fish per kg	6.89
Kg of fish caught in area	464,000
Market price of ornamental fish	2.45
Kg of ornamental fish caught in area	321,600
Environmental	
Tons of CO_2 absorbed by Amazon annually	1,700,000,000
% of Amazon cleared	0.0045%
Plant biomass tons per m2	0.02
KWh / Barrel of oil	1,699
Cost of CO_2 in 2015 (grows at 1.19% per year)	$25
Social	
Number of people displaced	30,000
Average family size	3.3
Number of houses accounted for	8,000
Price per house	13,230

Table 5.2, meanwhile, shows how the net costs and benefits vary year-to-year across the 50-year time horizon. Finally, Table 5.3 tables the lifetime cost and benefits broken down by sector and Figure 5.1 graphs the cumulative NPV of the project over the time horizon. Therefore, we see that the NPV of the Belo Monte Hydroelectric Dam Complex in the base case scenario is -$2,572,707,577.30. This implies that, from the perspective of 2011, with a 12% discount rate and with the best knowledge available today about the costs and benefits of Belo Monte, we would seriously consider not constructing the dam.

Arguably the biggest contributing factor to the -$2.5 billion NPV is the high upfront cost of constructing the dam. With such a high discount rate and with benefits only beginning in 2015, the construction costs are such that they cannot be overcome by the many future years of net benefits. Another key factor is the (perhaps absurdly) low price per MWh of the electricity supplied by the dam (as may have been expected from the fact that many large Brazilian energy companies did not even bid on the project due to worries about recouping their investment). In fact, this low price results in the energy revenue from the dam not even being the largest benefit. Instead, the cheapness of the electricity relative to other energy sources does the most to counteract the many costs. Interestingly, however, were the price of electricity supplied by Belo Monte to increase, the effect on energy revenue would increase, while the effect on the benefit related to Belo Monte as a cheap energy source would decrease by an equivalent amount. Thus, changes in the price of electricity supplied by Belo Monte have no effect on the final net present value – they only change the relative contribution of the two main benefits, revenue and hydroelectricity as a cheap energy source.

Table 5.2: Scenario A - Net Present Values by Year

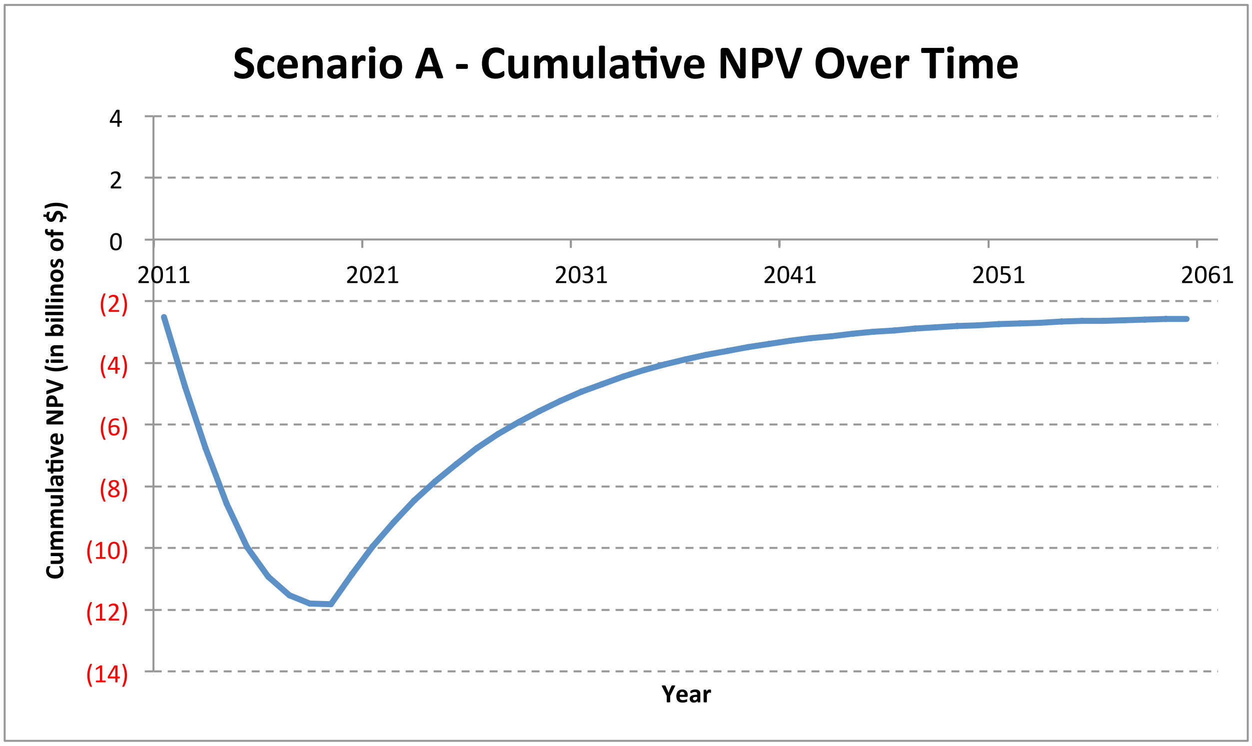
Year	Costs ($)	Benefits ($)	NPV ($)
2011	2,516,272,676	-	(2,516,272,676)
2012	2,246,672,032	-	(2,246,672,032)
2013	2,005,957,172	-	(2,005,957,172)
2014	1,791,033,189	-	(1,791,033,189)
2015	1,756,275,327	342,552,184	(1,413,723,142)
2016	1,570,852,895	612,692,816	(958,160,079)
2017	1,405,002,517	821,899,959	(583,102,559)
2018	1,256,748,235	980,099,329	(276,648,906)
2019	1,124,173,818	1,095,735,066	(28,438,751)
2020	7,998,263	992,421,888	984,423,625
2021	7,153,316	887,644,314	880,490,998
2022	6,397,822	793,953,704	787,555,881
2023	5,722,294	710,174,644	704,452,349
2024	5,118,253	635,256,539	630,138,286
2025	4,578,118	568,260,341	563,682,223
2026	4,095,115	508,346,687	504,251,572
2027	3,663,190	454,765,301	451,102,111
2028	3,276,929	406,845,528	403,568,598
2029	2,931,496	363,987,868	361,056,372
2030	2,622,566	325,656,418	323,033,852
2031	2,346,273	291,372,112	289,025,839
2032	2,099,162	260,706,688	258,607,525
2033	1,878,144	233,277,285	231,399,141
2034	1,680,458	208,741,630	207,061,171
2035	1,503,635	186,793,720	185,290,085
2036	1,345,468	167,159,978	165,814,510
2037	1,203,985	149,595,809	148,391,824
2038	1,077,420	133,882,523	132,805,103
2039	964,198	119,824,589	118,860,391
2040	862,909	107,247,177	106,384,268
2041	772,291	95,993,960	95,221,669
2042	691,217	85,925,157	85,233,939
2043	618,681	76,915,773	76,297,092
2044	553,779	68,854,036	68,300,257

2045	495,707	61,639,995	61,144,288
2046	443,744	55,184,263	54,740,519
2047	397,246	49,406,904	49,009,658
2048	355,636	44,236,428	43,880,792
2049	318,398	39,608,898	39,290,499
2050	285,073	35,467,130	35,182,056
2051	255,248	31,759,978	31,504,730
2052	228,554	28,441,696	28,213,142
2053	204,661	25,471,365	25,266,704
2054	183,275	22,812,384	22,629,109
2055	164,132	20,432,012	20,267,880
2056	146,995	18,300,961	18,153,966
2057	131,655	16,393,031	16,261,377
2058	117,921	14,684,783	14,566,862
2059	105,626	13,155,247	13,049,621
2060	94,617	11,785,661	11,691,044

Table 5.3: Scenario A - Net Present Values Broken Down by Category

Costs			**Benefits**		
Construction	$	14,985,406,526	Energy revenue	$	5,139,966,490
O&M		55,740,390	Pricing benefit		6,734,135,399
Fishing loss		26,549,149	Positive carbon footprint		1,301,261,866
Ornamental fish collection lost		6,543,280			
Displacement		9,569,924			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		15,748,071,332			13,175,363,755
Total NPV	**$**	**(2,572,707,577)**			

Figure 5.1



Scenario A - Cumulative NPV Over Time
4
2
0
(2)
(4)
(6)
(8)
(10)
(12)
(14)
2011
2021
2031
2041
2051
2061
Cummulative NPV (in billinos of $)
Year

Scenario B: Initial Budget

The Initial Budget scenario makes one key change to the Base Case: the dam does not run over budget, i.e. the overrun factor is 1 and the construction costs of the dam are thus equal to $11.3 billion. Scenario B's net present values for each category are presented in Table 5.4. Cumulative NPV over time is shown in Figure 5.2.

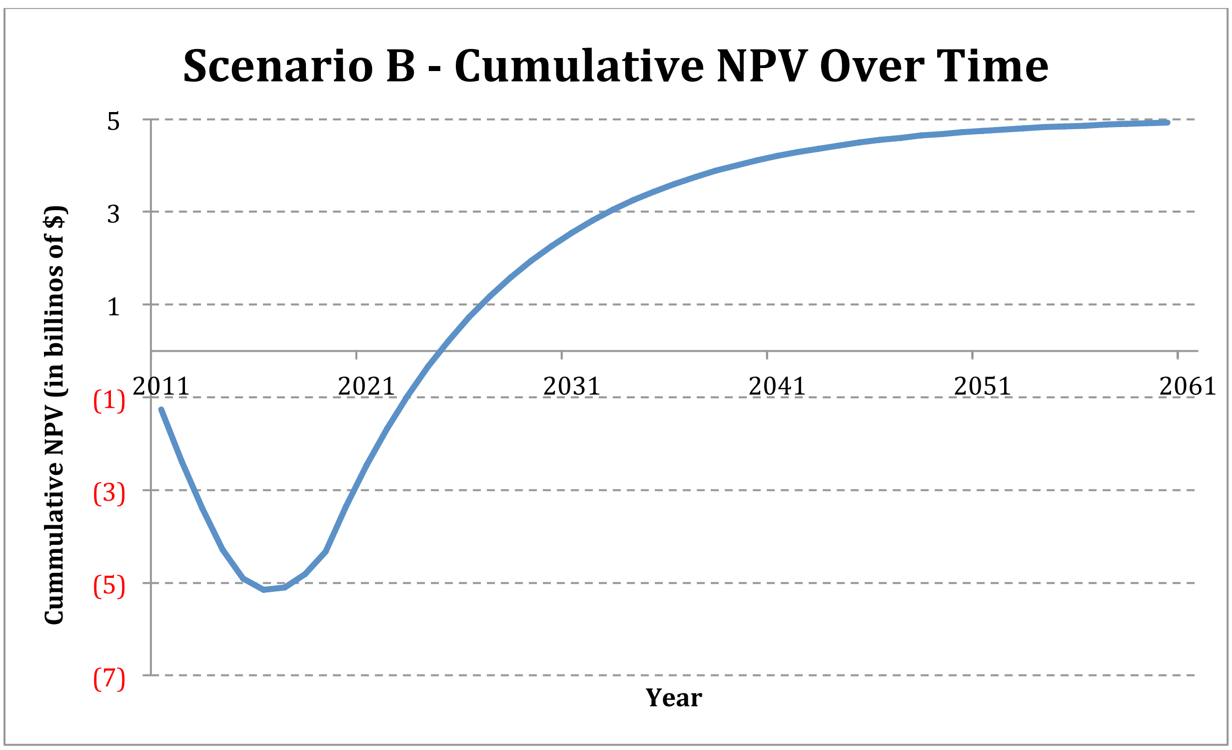
When Belo Monte's construction costs are equivalent to its initial budget, we see that the NPV is $4.9 billion. However, it is highly unlikely that Belo Monte will end up running according to budget. Though certain people (primarily members of the Brazilian government) still purport that the project will not run over budget, most sources make estimates that fall close to the construction costs we calculated for our Base Case scenario.

All else equal, in order for the NPV to be greater than or equal to zero, Belo Monte cannot exceed an overrun factor of 1.66. This is equivalent to construction costs of $18.6 billion.

Table 5.4: Scenario B - Net Present Values Broken Down by Category

Costs			**Benefits**		
Construction	$	7,492,703,263	Energy revenue	$	5,139,966,490
O&M		55,740,390	Pricing benefit		6,734,135,399
Fishing loss		26,549,149	Positive carbon footprint		1,301,261,866
Ornamental fish collection lost		6,543,280			
Displacement		9,569,924			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		8,255,368,069			13,175,363,755
Total NPV	**$**	**4,919,995,686**			

Figure 5.2



Scenario C: Longer Construction Period, Increased Overrun Factor

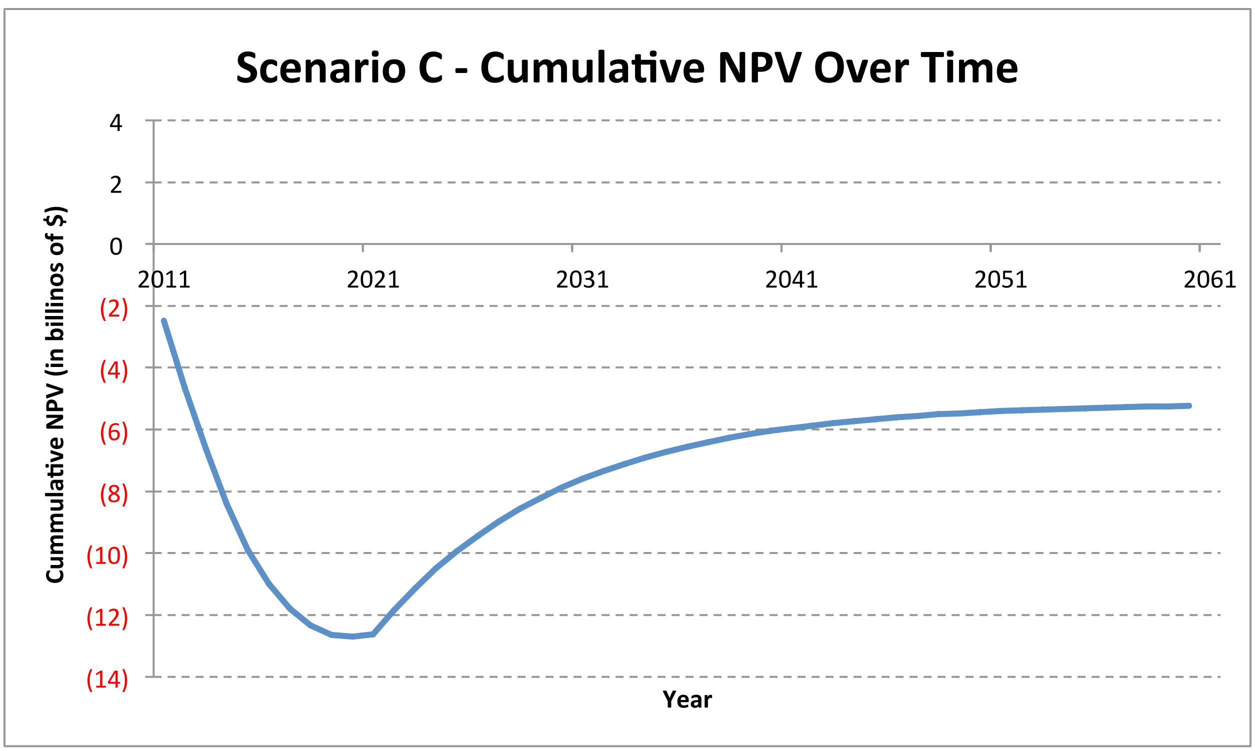
In Scenario C, we assume that the construction period now lasts eleven years instead of nine – a two-year increase. Since a longer construction period absent an increase in the overrun factor results in a higher NPV, we make the added assumption that the overrun factor increases to 2.4, the overrun factor of Itaipu Dam. Scenario C's net present values for each category are presented in Table 5.5. Cumulative NPV over time is shown in Figure 5.3.

Thus, we see that Scenario C results in a NPV of -$5.2 billion. Of all of our scenarios, Scenario C is perhaps the most likely, as Belo Monte has already been delayed several times by, for instance, legal disputes or strikes.

Table 5.5: Scenario C - Net Present Values Broken Down by Category

Costs			**Benefits**		
Construction	$	16,395,822,594	Energy revenue	$	4,639,399,563
O&M		44,326,376	Pricing benefit		6,078,316,830
Fishing loss		26,549,149	Positive carbon footprint		1,193,355,235
Ornamental fish collection lost		6,543,280			
Displacement		8,725,532			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		17,146,228,994			11,911,071,628
Total NPV	**$**	**(5,235,157,366)**			

Figure 5.3



Scenario D: Slightly Improved Capacity Factor

For Scenario D, we will assume that Belo Monte reaches a capacity factor of 56% as opposed to the 40.7% originally predicted. The 56% is equivalent to the average capacity factor of large (>30MW) hydroelectric dams in Brazil. Scenario D's net present values for each category are presented in Table 5.6. Cumulative NPV over time is shown in Figure 5.4.

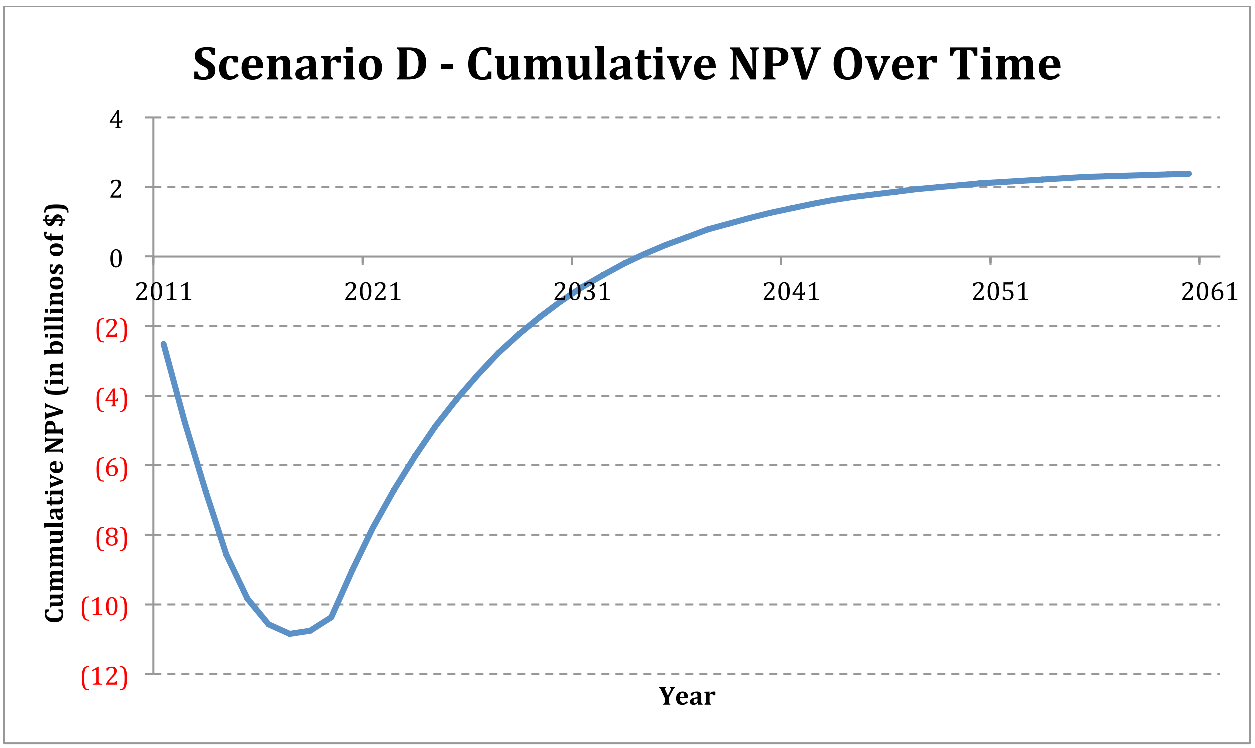
Scenario D results in a NPV of $2.4 billion. As we can see, you do not need a 15.7% increase in its capacity factor in order to be NPV positive (all else equal). In fact, Belo Monte could have a lower than average capacity factor relative to other large dams in Brazil and still be NPV positive; Belo Monte's capacity factor needs only to increase to 48.65% to be NPV positive.

There are several ways to increase the capacity factor. One, were the reservoir enlarged through the construction of more dams along the Xingu River, Belo Monte would be able to draw water from a larger source and thus run closer to its installed capacity. Of course, this benefit of constructing more dams may be outweighed by the costs of building these extra dams. Second, increases in rainfall would also lead to a larger reservoir and thus lead to a higher capacity factor. However, average rainfall over a timespan as large as fifty years is likely to be similar to historical averages, and historical averages were used to predict the original capacity factor of 40.7%.

Table 5.6: Scenario D - Net Present Values Broken Down by Category

Costs			**Benefits**		
Construction	$	14,985,406,526	Energy revenue	$	7,072,189,766
O&M		55,740,390	Pricing benefit		9,265,640,843
Fishing loss		26,549,149	Positive carbon footprint		1,790,434,017
Ornamental fish collection lost		6,543,280			
Displacement		9,569,924			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		15,748,071,332			18,128,264,626
Total NPV	**$**	**2,380,193,294**			

Figure 5.4



Scenario E: The Miracle, Maximum Capacity

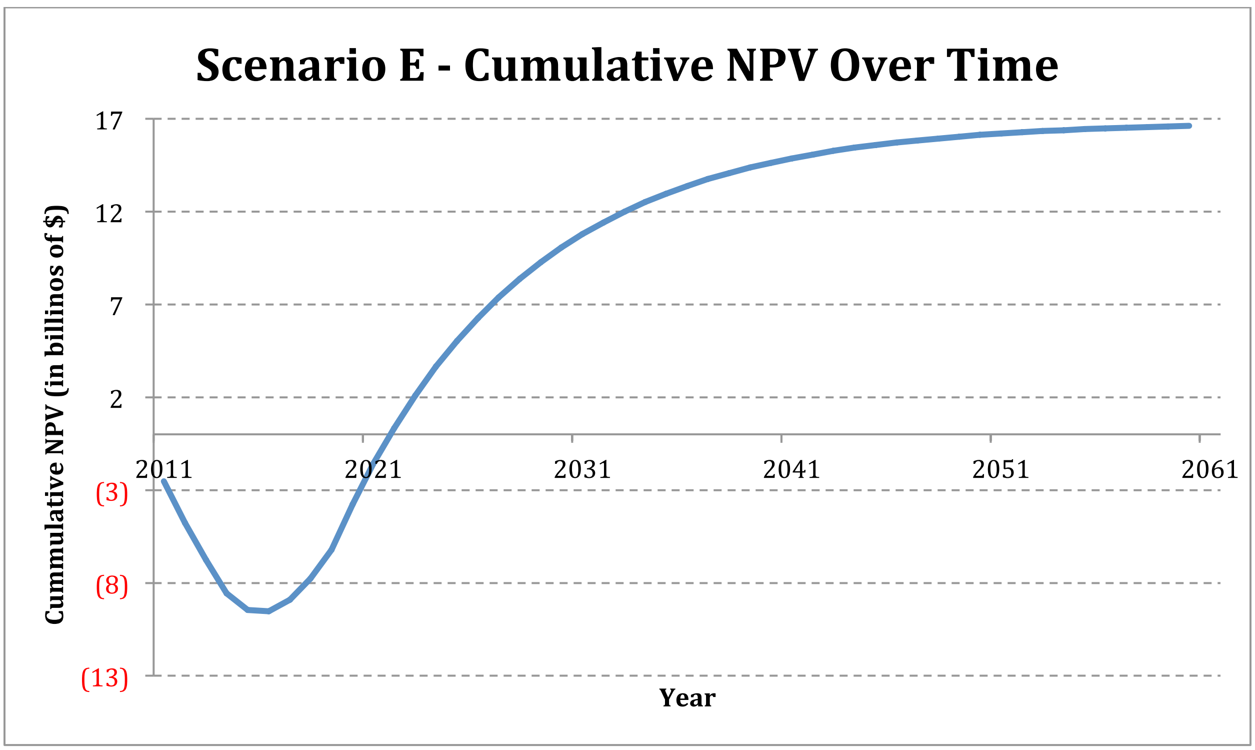
Scenario E assumes that the dam will operate at full installed capacity over the entire fifty years. The scenario is little more than a thought experiment – it serves to provide a type of upper bound for our analysis. Scenario E's net present values for each category are presented in Table 5.7. Cumulative NPV over time is shown in Figure 5.5.

Maximum capacity power production results in a NPV of $16.6 billion. Again, this figure is purely hypothetical. Even Itaipu Dam, one of the most efficient mega-dams in the world, runs at a capacity factor of 75%.

Table 5.7: Scenario E - Net Present Values Broken Down by Category

Costs			**Benefits**		
Construction	$	14,985,406,526	Energy revenue	$	12,628,910,296
O&M		55,740,390	Pricing benefit		16,545,787,220
Fishing loss		26,549,149	Positive carbon footprint		3,197,203,601
Ornamental fish collection lost		6,543,280			
Displacement		9,569,924			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		15,748,071,332			32,371,901,117
Total NPV	**$**	**16,623,829,785**			

Figure 5.5



Scenario F: Extreme Weather and the Possibility of Droughts

Another scenario that we will run includes the possibility of extreme weather, specifically droughts. The decrease in rainfall and low river conditions associated with droughts leads to dams having lower power production. This issue is certainly applicable to Belo Monte, a dam that already suffers from a very low current during the two dry months of the year.

Brazil has experienced four major droughts in the past two decades – one in 1997-98, another in 2005, a third in 2010, and a fourth that is currently ongoing and considered to be the worst in eight decades (extreme rainfall and flooding also affected the country in 2011)[c]. Projections of future rainfall levels in the Amazon differ by region and change over time. The northern part of the Amazon, where Belo Monte is located, is projected to become more vulnerable to extreme dryness and droughts over the course of the 21st century due to shifts in the world's air circulation and the potential acceleration of climate change[ci]. Therefore, it is possible that our base case scenario is too optimistic regarding the dam's power production, since lower water levels and thus lower reservoir levels will decrease the dam's overall power generation capacity. Hence, in this scenario, we incorporate the possibility of droughts.

For Scenario F, there are two key assumptions. First, we assume that there will be a drought in Brazil roughly every four years (with the first drought in 2018). We took this number from the cited study from the University of Texas at Austin[cii]. Second, we will assume that a year that includes a drought drops the average power production of Belo

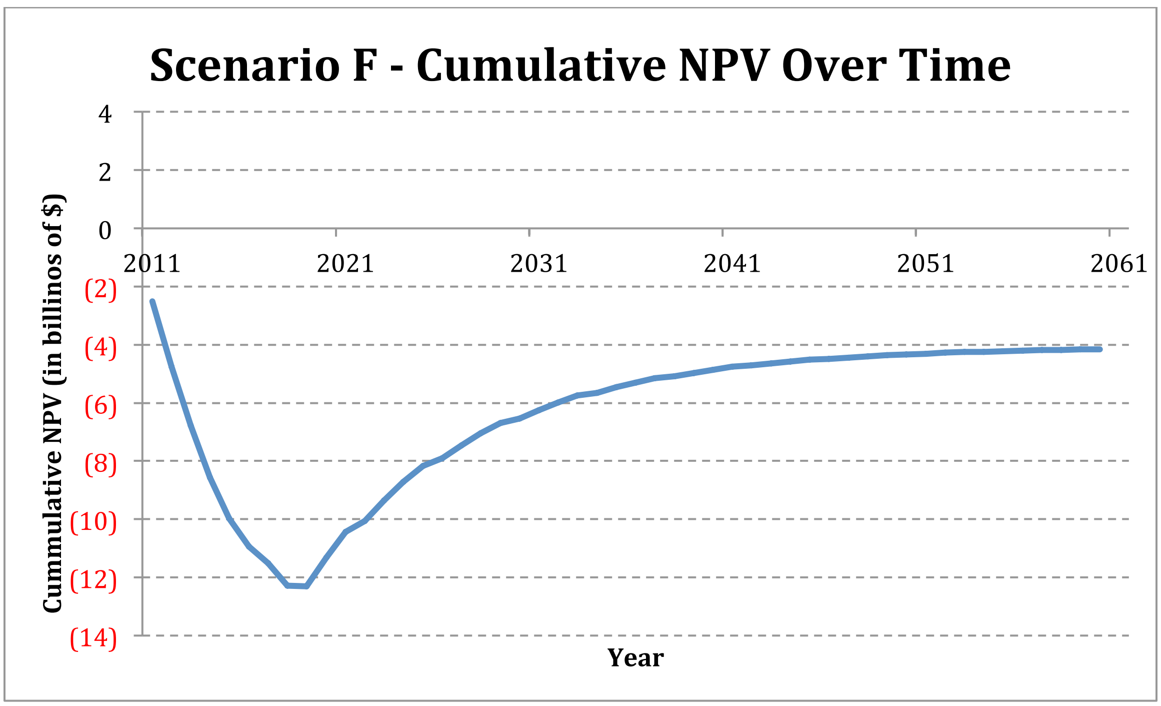
Monte by 50%. Unfortunately, there is little information available about how droughts have affected Brazilian dams' power production in the past, so this number was chosen arbitrarily. However, the importance of this scenario is to analyze the general hypothetical of frequent droughts. Scenario F's net present values for each category are presented in Table 5.8. Cumulative NPV over time is shown in Figure 5.6.

Scenario F results in a NPV of -$4.2 billion. As expected, the NPV of the dam decreases as a result of the introduction of possible negative shocks to average power production. Droughts accomplish this by decreasing all three benefits (energy revenue, cheaper energy source, positive carbon footprint) while not affecting costs whatsoever. Interestingly, it took only eleven occurrences of drought to almost double the negative NPV relative to the Base Case.

Table 5.8: Scenario F - Net Present Values Broken Down by Category

Costs			Benefits		
Construction	$	14,985,406,526	Energy revenue	$	4,523,105,004
O&M		55,740,390	Pricing benefit		5,925,953,326
Fishing loss		26,549,149	Positive carbon footprint		1,143,928,422
Ornamental fish collection lost		6,543,280			
Displacement		9,569,924			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		15,748,071,332			11,592,986,752
Total NPV	$	**(4,155,084,580)**			

Figure 5.6



Scenario G: Decrease in Price of Alternatives

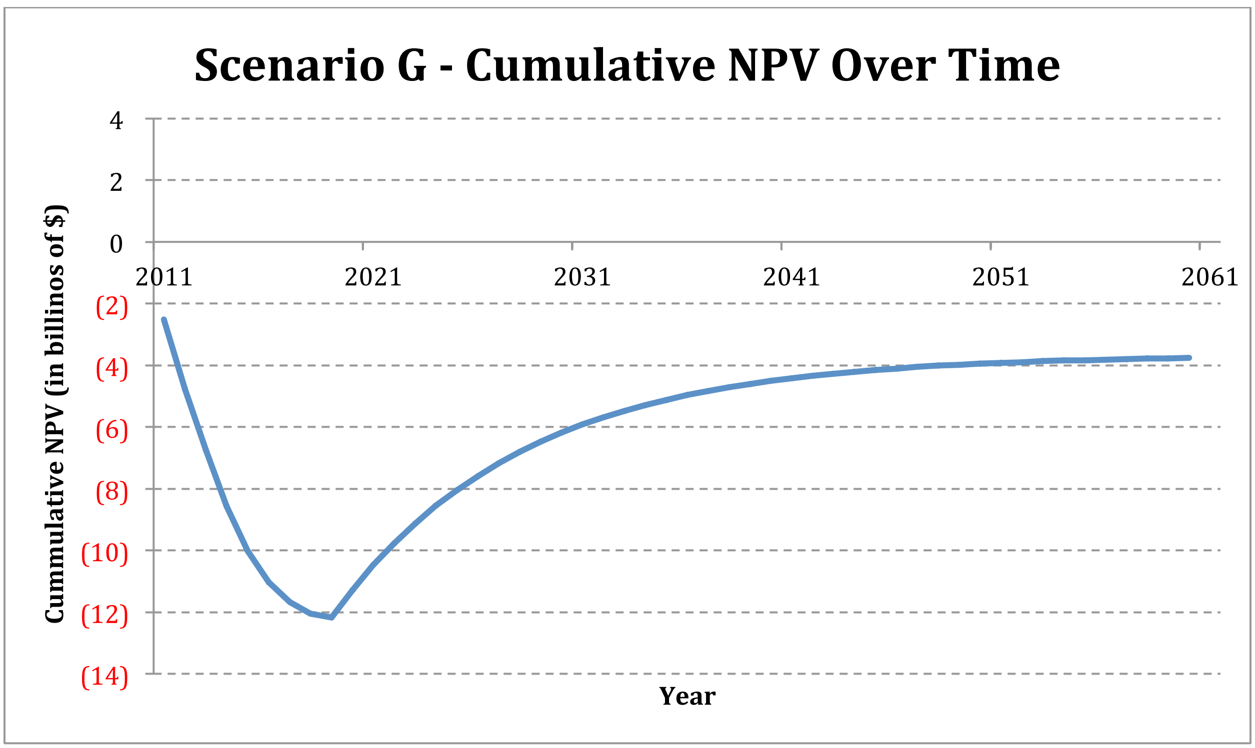
Scenario G assumes that the weighted average alternative price per MWh discussed in "Economic and Financial Costs and Benefits" decreases by 10% (from $70.09/MWh to $63.08). Scenario G's net present values for each category are presented in Table 5.9. Cumulative NPV over time is shown in Figure 5.7.

The net present value for Scenario G is -$3.8 billion. The average alternative price decrease that drives this decrease in NPV may occur due to shifts in the weighting of the alternative energy sources or due to decreases in the price of alternatives. Currently, the highest weight in our calculation of the average alternative price is assigned to fossil fuels, which also have the second highest price per MWh. If Brazil pursues a policy of decreasing fossil fuel's relative contribution to energy production, we will thus see a decrease in the weighted average alternative price. Another trend that could lead to decreases in the weighted average price of alternatives is the decrease in price per MWh of non-hydroelectric renewables such as solar or biomass. It is not a stretch to assume that these renewable sources of energy will become more prevalent and more technologically advanced, and thus become cheaper.

Table 5.9: Scenario G - Net Present Values Broken Down by Category

Costs			**Benefits**		
Construction	$	14,985,406,526	Energy revenue	$	5,139,966,490
O&M		55,740,390	Pricing benefit		5,546,555,798
Fishing loss		26,549,149	Positive carbon footprint		1,301,261,866
Ornamental fish collection lost		6,543,280			
Displacement		9,569,924			
Foregone CO2 Absorption		12,064,640			
Methane and CO2 Emission		652,197,422			
		15,748,071,332			11,987,784,154
Total NPV	**$**	**(3,760,287,178)**			

Figure 5.7



Discount Rate Sensitivity Analysis

We conducted a discount rate sensitivity analysis, using a range 8% through 16%. Table 5.10 shows the net present value of each scenario and for each discount rate.

Table 5.10: NPV of Scenarios Across Discount Rates

		Discount rate					
		8%	10%	12%	14%	16%	8% - 16%
Scenario	A	5,962,367,694	675,141,917	**(2,572,707,577)**	(4,617,279,953)	(5,922,547,873)	11,884,915,567
	B	14,433,147,701	8,628,993,699	**4,919,995,686**	2,462,626,936	786,627,362	13,646,520,339
	C	2,229,841,300	(2,473,311,015)	**(5,235,157,366)**	(6,873,899,650)	(7,839,131,625)	10,068,972,925
	D	14,959,715,252	7,240,184,543	**2,380,193,294**	(779,619,806)	(2,884,468,047)	17,844,183,299
	E	40,834,440,254	26,120,045,690	**16,623,829,785**	10,256,788,462	5,852,493,543	34,981,946,711
	F	3,051,415,386	(1,436,328,339)	**(4,155,084,580)**	(5,834,531,728)	(6,878,832,191)	9,930,247,578
	G	3,819,031,993	(894,512,476)	**(3,760,287,178)**	(5,539,492,008)	(6,653,883,230)	10,472,915,223

The table above illuminates several interesting points about our analysis of Belo Monte. First, when using a discount rate of 8%, every scenario has a positive NPV. While this rate is far below the 12% we used for most of our analysis, it is interesting to note that simply decreasing the risk profile of the country (or alternatively worded, decreasing the average rate of return on investments in Brazil) has such a dramatic effect on the NPV of the project. We used the difference in NPVs at 8% and 16% as a proxy for the sensitivity of each scenario to changes in the discount rate. Five scenarios fall within a $3.7 billion band, ranging from $9.9 billion to $13.6 billion. The two outliers, Scenarios D and E with differences of $17.8 billion and $35.0 billion respectively, are both scenarios in which the average power production of the dam is increased. While Scenario F's difference of $9.9

billion was not an outlier, it set the lower bound to our sensitivity analysis. As with Scenarios D and E, Scenario F deals with changing average power production, except this time in the opposite direction. Therefore, it seems as though changes in average power production are the most sensitive to changes in the discount rate relative to other possible changes in inputs.

In general, the data in Table 5.10 seems to support the idea that Belo Monte is likely to be a negative NPV project. Only the incredibly unlikely scenarios turn positive NPV at a 10% discount rate, and while an 8% discount rate does make all scenarios positive NPV, a drop from 12% to 8% seems quite large for a country growing as rapidly as Brazil is currently. In the range of 10% - 14%, the typical negative NPV is in the several billions. The notoriety of Belo Monte and the heaps of negative attention surrounding the dam do seem to be justified.

VI. CONCLUSION

The value of scenario-based analysis is in allowing us to build a robust model to determine the likely effects of the dam across a wide range of parameters. From the seven scenarios examined, holding the discount rate constant, we see that four of the scenarios result in negative NPVs, with the smallest still standing at a sizeable -$2.5 billion. Of the three positive cases, it is worth immediately dismissing the miracle scenario, Scenario E, which uses the 100% capacity factor assumption – this is unrealistic given the performance of similar dams around the world. Of the two remaining positive NPV scenarios, the first, Scenario B uses the assumption that the final budget is equal to the proposed budget. The second positive scenario, Scenario D uses a capacity factor in line with the Brazilian average for large dams (> 30MW). Of these two assumptions, Scenario D is the more likely, though, given problems with rainfall and water flow, Scenario D seems to be a stretch as well.

The largest negative scenario, Scenario C, assumes a two-year increase in the total construction period. Additionally, Scenario C assumes an increase in the overrun factor of construction costs to 2.4. This is not an unrealistic assumption given the delays in construction at Belo Monte so far. The next largest negative NPV scenario, Scenario F, factors in the probability of droughts. Given that Brazil is currently in a drought and experiences one approximately every four years, this ought to be a serious consideration. Scenario G assumes that the price of alternative energy sources decreases, eroding the advantage that hydroelectric power has over them. Considering Brazil’s determination to

move to cheaper renewables, as well as the effect technological advance should have on the price of such renewables, this too seems a reasonable assumption. Finally, in Scenario A, our Base Case, the default assumptions still lead to a large, negative NPV. Therefore, it seems that all scenarios that run reasonable assumptions support the Base Case; Belo Monte is likely to be a negative NPV project.

Of course, the aforementioned cases are for the discount rate of 12%. In the sensitivity analysis, we varied the discount rate. A decrease in the discount rate to 8% results in all scenarios being positive NPV, while a decrease to 10% turns the Base Case into a positive NPV scenario. By contrast, if the discount rate were to increase to 14% or 16%, there would only be two positive scenarios: Scenarios B and E. Scenarios B and E are positive across all the discount rates we tested. Recall, however, that B and E are highly unlikely (almost impossible, in fact) scenarios.

One further area for discussion is the unquantifiable costs and benefits, which were not included in the NPV analysis. The value of the dam will be affected by more than just the inputs included in the analysis, by factors that are either unknown or difficult to predict. What, for instance, might be the eventual long-term effect of the political cost to the Brazilian government? Perhaps the credibility of the government might be damaged to the point where the next large infrastructural investment is met with far greater skepticism and resistance. This could have a significant but unpredictable effect on the growth prospects of Brazil going forward. Unquantifiable factors should not be ignored because they cannot be quantified, and will be fruitful questions to consider when

evaluating the performance of the dam in the future. While the unquantifiable results will have both positive and negative effects, it is not inconceivable that there are more unknown negative results than positive, based on preceding analysis.

Two final considerations must be noted. First, could Brazil meet its growing energy demand by increasing energy efficiency? A WWF-Brazil report in 2007 estimated that Brazil could cut its demand for electricity by 40% by 2020 by investing in energy saving technologies. Second, some have argued that greater investment in other types of renewables, such as wind or nuclear power, could achieve, at a lower price, similar outcomes to hydroelectricity. As the energy demands for Brazil continue to go up, both of these options may require revisiting.

Given both Brazil's burgeoning demand for energy and insistence on filling this demand with domestic sources of renewable energy, a large infrastructural project such as Belo Monte that was capable addressing both issues was highly likely. Based on the assumptions we have described, we expect the Belo Monte Dam to be a costly infrastructural project, with likely negative Net Present Value. Brazil has precedent; as discussed throughout the paper, Itaipu Dam was extremely costly, but has still been a vital source of energy to the nation. A similar end for Belo Monte is certainly plausible, but especially contingent on construction costs and the variability of rainfall and thus the reservoir level. While neither strictly negative nor positive, Belo Monte is nearing completion, and only time will tell if the dam's numerous detractors are proved correct.

VII. CONTRIBUTIONS

Apratim Guatam: Apratim conducted researched for and wrote the "Dam Technology" section, wrote the three subsections on unquantifiable costs and benefits, jointly wrote the "Conclusion" section, and edited the paper.

Ian Haubold: Ian created the Excel model used to run all our scenarios, created all tables and figures in the "Analysis" section, wrote the "Financial and Economic Costs and Benefits" subsection, and wrote the "Discount Rate Sensitivity Analysis" subsection.

Vicky Pacey: Vicky conducted research for the "Social and Political Costs and Benefits" subsection and created the bibliography.

David Papirnik: David conducted research for and wrote the "Introduction" section, conducted research for and wrote most of the "Cost-Benefit Input" section, wrote the "Analysis" section, jointly wrote the "Conclusion" section, and edited the paper.

Mehek Premjee: Mehek conducted research for the "Environmental Costs and Benefits" subsection.

Patrick Schlumpf: Patrick conducted research for the subsections "Economic and Financial Costs and Benefits" and "Social and Political Costs and Benefits."

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