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BRAZIL'S ENERGY DIVIDE: SUSTAINABLE ENERGY ALTERNATIVES FOR THE BRAZILIAN AMAZON REGION

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ABSTRACT
The insertion of the Brazilian Amazon region into the Brazilian and global economies is one of the challenges faced by the Brazilian economy. Accounting for 60% of the Brazilian territory, the region will play a key role in shaping the future growth and development of the Brazilian economy in the next decades. Energy availability has been the region's main economic bottleneck. The energy divide refers to the lack of adequate and reliable energy supply in the Amazon region and constitutes the region's main barrier for its further economic development and growth. The lack of energy imposes limitations on the local population standards of living, increases the business costs, limits the economic exploration, and limits its business vocations. The region's energy matrix carries a substantial carbon footprint, since most of the region's energy needs are filled by fossil fuels. This paper discusses energy solutions and alternatives for the Brazilian Amazon region.
Keywords: Amazon, energy, green economy, sustainability.

1 INTRODUCTION

The Brazilian Amazon region has been largely recognized for its economic potential and its global environmental importance. Since the early 1990s, sustainable development economic policies have been prescribed to unleash the region's economic and environmental potentials. However, the lack of energy has been a meaningful barrier to the sustainable development of the Amazon region [1–4].

In 1972, the 'Bruntland Report' introduced the discussion on the importance of implementing and following sustainable development strategies. In 1992, the United Nations Conference on the Environment and Development (UNCED) further advanced the agenda for the introduction of sustainable development strategies. In 2009, the 15th Conference of the Parties (COP 15) under the UN's Framework Convention on Climate Change (UNFCCC) was able to gather 110 countries pledging to lower greenhouse gas (GHG) emissions. For instance, Brazil pledged to lower deforestation levels in the Amazon region and to stop deforestation in the Amazon region altogether by 2020. Despite the lack of consensus on the levels of climate finance, targets for emissions reductions and introduction of a new treaty to replace or upgrade the Kyoto Protocol, the conference was successful in creating a new momentum for the discussion of sustainable economic development strategies.

Sustainable development strategies offer the avenue for the allegedly contradictory goals of development and environmental protection. These strategies echo trends toward better environmental policies, investment on environmentally friendly technologies and promotion of economic development strategies embodying environmental concerns.

Nowadays, one of the challenges for the further establishment of sustainable economic development strategies, as it was demonstrated in the 2009 COP15 summit, is to design multilateral alternatives to develop global cooperation in a new environment in which national interest contributes to the strengthening of the globe's environmental efforts, while respecting the sovereign rights of each country.

Increasing business integration of the Brazilian Amazon region into the Brazilian and global economies is inevitable. In the process, the Brazilian Amazon region will offer immense business opportunities for Brazilian and foreign companies willing to develop environmentally friendly technologies with sensitivity to the region's environmental specificities. However, the Amazon region's current

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energy matrix is heavily dependent on fossil fuel. Developing a 'greener' energy matrix will contribute to the design and development of sustainable economic development strategies for the region.

2 BRAZIL'S ENERGY CHARACTERISTICS

Brazil's continuous quest for economic development and growth imposes increasing pressure on the country's energy matrix. In 2010, the Brazilian energy matrix reflects a number of policies and strategies pursued in the past decades heavily stressing on hydro and biomass sources of energy. As a result, the Brazilian energy matrix is very unique in relation to other developed and emerging economies. For instance, Brazil's high reliance on renewables positions the country well above other nations. The country's heavy reliance on biomass and electricity ranks Brazil quite high on the 'green energy matrix' scale [5, 2, 6, 7, 4].

Brazil is the largest energy consumer in Latin America. It ranks 3rd in the hemisphere and 10th in the world after France and the United Kingdom. Brazil's demand for electricity is expected to grow at 3% annually from 2005 to 2020 [1, 2, 4].

Brazil's energy matrix is bi-dimensional in nature, centralized, covers vast distances, and suffers substantial transmission losses. Brazil's economy and society is served by interconnected and isolated energy systems. The country also suffers from an energy divide, that is, 12 million Brazilians have no access to electricity, mostly living outside the interconnected electricity grid, illustrating the potential for decentralized energy (DE) solutions [8–14].

Table 1, illustrates Brazil's energy matrix's expected evolution for the period 2004–2010. In 2005, Brazil had 1,424 energy-generating enterprises with a total installed power of 90.7 Gigawatt (GW). In the next five years, an additional 31.7 GW will be added to the country's generation capacity. By 2030, it is expected that the share of natural gas will increase to 15.5%, and renewables to about 9.1% of Brazil's energy matrix. It is also noteworthy to note that nuclear power will increase its share from 1.4% in 2007 to about 3.0% by 2030.

Natural gas is expected to increase its participation in the country's energy matrix. Brazil has 12.9 trillion cubic feet (TCF) of proven natural gas reserves in 2009, the fourth largest in Latin America, after Venezuela, Bolivia, and Argentina. The completion of the transnational pipeline (BTB), a US $1.8 billion project, linking Bolivia to Brazil and other pipelines from Argentina is increasing the share of natural gas in Brazil's energy matrix. The 'Gasbol' pipeline brings gas from Bolivia to Brazil; natural gas imports have expanded from 400 million m^3 in 1999 to about 9.3 billion m^3 in 2006 [15].

Brazil's recent 'Pre-Salt' oil and gas discoveries are also bound to change the country's energy matrix in the next decades (Lozardo, 2009) [16, 17]. In 2009, Brazil had proven oil reserves of 12.6 billion barrels, second only to Venezuela in South America. In 2010, oil production should reach

Table 1: Brazil's energy matrix, 2004–2010.

	2004	2010
Petroleum (%)	39	35
Natural gas (%)	9	15
Hydro power (%)	14	11
Biomass (%)	13	12
Sugarcane (%)	13	15
Others	12	12

Source: Anuario Exame, 2005–2006; Almeida, 2010.

Table 2: Brazil's electricity generation matrix (MW), 1990–2030.

	1990	2000	2020	2030
Coal	5	10	18	30
Oil	6	17	16	12
Gas	0	2	104	226
Nuclear	2	6	21	21
Hydro power	207	305	507	589
Other renewable*	4	9	19	32

*wind, biomass, PV

Source: International Energy Agency (2005); Almeida (2010).

2.81 million bbl/d. However, a number of challenges will have to be overcome before these oil reserves become available. In addition, the British Petroleum environmental disaster in the Gulf of Mexico will bring additional scrutiny in Brazil's 'Pres-Salt' oil explorations [15].

In 2007, Brazil's interconnected energy system had 96.6 GW of installed power capacity. The transmission network comprises of 184,000 km of lines, managed by the National Operator of the Electricity System (ONS). Brazil's continental dimensions also leads to dramatic transmissions losses, close to 16%, compared to 8% for the US electrical system [15, 18, 19].

Brazil's Southeast, Northeast, and Mid-west regions are served by the interconnected energy system. The Brazilian Amazon region, on the other hand, is heavily dependent on the isolated system. The isolated system is mostly supplied by small-scale energy grids, heavily dependent on diesel generators. The Amazon region accounts for only 2% of Brazil's energy consumption, pointing to a repressed energy demand in the region [8, 10, 20].

The country's reliance on hydro power and biofuel makes the Brazilian energy matrix one of the world's least carbon intensive. In addition, the use of ethanol combined to hydro power also makes Brazil one of the world's smallest producers of GHGs, about one-fourth of the value in the United States. Moreover, 44% of Brazil's energy matrix is made of renewable energy, compared to a world's average of 14% [1, 2].

Between 1995 and 2004, Brazil's installed capacity jumped from 57.6 to 90.7 GW. In the last three decades, Brazil has seen its energy consumption expand faster than its GDP. In the last three decades, Brazil's population doubled, its GDP tripled, and Brazil's electrical consumption expanded by eight times. Despite of its increasing growth, Brazil's electrical consumption per capita is still very low, around 2,000 kW-h/year [15, 4, 21].

Table 2 highlights the evolution of the Brazilian electricity generation matrix. Natural gas and hydro power are expected to generate most of Brazil's needs in the next three decades. In addition, renewables are also expected to increase their share in Brazil's total energy generation.

3 BRAZIL'S ENERGY POLICIES AND PROGRAMS

The 1988 Brazilian Constitution made the availability of energy to the Brazilian population a priority, an essential public service. Since then, the Brazilian federal Government has called upon itself the responsibility to provide the service. After 1988, the energy divide has received more attention from Brazilian policymakers. Brazilians living in rural areas are the main victims of the energy divide [22–25].

Energy supply raises the standard of living by making lighting, healthcare, telecommunications, clean water, and educational services available. Poverty and lack of energy go together. Energy supply also allows for the creation of new jobs and fosters entrepreneurship in rural communities (Leite, 2009) [26, 27].

Table 3: Brazil's energy divide: access to electricity, Brazil 2000.

	Urban	Rural population	Total
Millions of people	136	31	167
W/Electric lighting	135	22	157
W/out Electric lighting	1	9	10
Electrification rate (%)	99	69	93

Source: IBGE, Brasil em Numeros, 2002. Rio de Janeiro: IBGE.

However, it is important to make energy supply affordable to rural communities. The existence of energy *per se* does not assure economic development. The low income of these communities is still a major barrier for energy access, if conventional energy platforms are used. In addition, the high cost of transmission lines and the small size of these energy markets tend to prevent the dissemination of energy usage by rural communities [28, 29, 20, 13, 30].

Brazil's rural market is characterized by its large dispersion, which makes the supply of energy through connections to the national grid extremely expensive.

The Brazilian energy privatization programs did not properly addressed the energy divide. As a result, it lacked the instruments and policies to entice private distribution companies to supply energy to rural areas. Table 3 illustrates the dimension of Brazil's energy divide. In 2000, Brazil had close to 10 million people without access to electricity, limiting their economic potential [31, 32, 7].

The new Brazilian energy model was shaped in 1993. Three regulatory agencies were created: ANNEEL, ANA, and ANP. The new Brazilian electricity model shows the following characteristics:

(a) Larger number of energy agents after privatization
(b) Competitive generation and distribution, regulated monopolies on transmission systems
(c) Foreign investor restrictions removed
(d) Regulated prices and tariffs

The 2002 Law 10438 introduced a number of changes in the Brazilian energy sector structure. The new changes stipulated the service obligations of distribution concessionaries, paying heed to the energy divide.

The Brazilian government has launched three major federal programs to address the issue of 'energy divide'. These programs address the issue of bringing electricity to rural and poor regions of Brazil: (a) PRODEEM; (b) Luz no Campo, and (c) Luz Para Todos. In addition, the National Bank of Social and Economic Development (BNDES) is also aiding the rural electrification effort [15, 33, 34, 4].

3.1 PRODEEM (1994): Programa de Desenvolvimento Energetico de Estados e Municipios (Electricity Development Program for States and Municipalities)

Programa de Desenvolvimento Energetico de Estados e Municipios (PRODEEM) is the main federal energy program promoting off-grid energy projects and programs. Established in 1994, it receives financial and technical aid from international organizations, which are implemented by Brazilian energy companies. The program relied on a number of pilot projects mostly using photovoltaic (PV), wind, hybrid systems, and biofuel energy solutions. Instead of supplying energy to households, the project concentrates on schools, hospitals, and other community projects.

The project has however faced a number of problems: (a) lack of skilled personnel in the communities to provide repairs, (b) no cost recovery schemes, and (c) lack of oversight and responsibility by local communities.

3.2 Luz no Campo Program (1999) (Electricity in Brazil's Countryside)

In 1999, the Luz no Campo program was launched to address some of the limitations of the PRODEEM program. This program relied mostly on grid extension projects and programs. Its main goal is to provide energy to 1 million households by 2007.

In 2002, the Brazilian Congress approved Law 10438 that created the Energy Development Account, creating a national energy fund that also promoted the use of innovative and alternative sources of energy. However, the programs still lacks the incentives for companies to promote connections to off-grid projects.

3.3 Luz Para Todos Program (2003) (Light for All Program)

The Luz Para Todos Program was launched in 2003. The program envisions alliances between the federal and state governments and energy companies (concessionaires). Investments of US $843 million are planned for this program. The goal is to supply energy to 12 million people affected by the energy divide.

4 BRAZIL'S RENEWABLE/ALTERNATIVE ENERGY EFFORTS

Brazil's interest in renewable/alternative sources of energy goes back to the mid-1970s. Brazil's extreme dependency on foreign oil made policymakers to devise renewable/sustainable alternatives to lower the country's dependency. Thus, since 1975, Brazil has been promoting the use of biofuel, such as ethanol, to replace gasoline [6, 35, 10, 36].

Brazil's large territory, geographical location, and climate make it a natural market and producer for alternative/renewable sources of energy. For instance, Brazil is a prime producer of biomass energy, such as biofuel like ethanol. Currently Brazil's main sources of biomass are sugarcane products, such as ethanol and biogases. In addition, residues, such as forest residues and sawmill residues can also be used to generate electricity [37, 26, 38].

Brazil's ethanol program, derived from sugarcane, is used in two major ways: one as a gasoline additive (anhydrous alcohol) and another as fuel replacing gasoline (hydrated alcohol). Brazil invested close to US $5 billion between 1975 and 1990 in the ethanol industry, agriculture, and manufacturing. Brazil saved close to US $53 billion with foregone imports of crude oil. Brazil's increasing efforts to develop indigenous technology coupled with economies of scale and high industrial and agricultural productivity have made the Brazilian ethanol industry very competitive on a global scale. Currently, Brazil has 3.5 million vehicles running on pure hydrated ethanol. In 2004, Brazil produced 350,000 flex-fuel cars [12, 4, 13, 39].

Brazil's interest in renewable/alternative sources of energy to generate electricity is very recent. Until 2001, the Brazilian government had no incentives in place to foster the development of indigenous technology and the implementation and use of these technologies.

The first initiative took place in 2001, through Resolution 24/2001. This Resolution created 'Proeolica' fostering the use of wind energy. Currently, Brazil has close to 21.2 megawatt (MW) of wind power installed. In 2002, Law 10438 established Proinfa, further reinforcing public support to renewable/alternative sources of energy programs and policies. These initiatives aim at adding additional energy supply to Brazil's energy matrix.

Proinfa is adding wind, biomass, and small hydro plants to Brazil's energy matrix. The goal is to have these renewable/alternative sources of energy accounting for 10% of Brazil's energy matrix by 2020 [40, 18, 41].

Energy independence, low environmental impact, use of local resources generating local employment, and income in isolated communities are all factors promoting and fostering the use of renewable sources of energy in Brazil's small communities.

Still, Brazil faces a number of barriers to the further utilization of alternative sources of energy, such as high initial costs and small-scale production of equipment and systems. In addition, the lack of skilled technicians to provide after-sales maintenance is also a major barrier. The lack of income in rural communities also makes access to energy an issue. Moreover, entrepreneurial projects aiming at generating income in rural, isolated communities need to be implemented in parallel to alternative/sustainable energy programs [28, 42–44].

5 ADDRESSING THE AMAZON REGION ENERGY DIVIDE

The lack of an abundant and sustainable supply of electricity has been a meaningful barrier to the further development of Brazil's Amazon region. This energy situation has kept a lid on the region's standard of living, increasing the costs and imposing bottlenecks on the region's business vocations [8, 3, 45].

The Amazon region is Brazil's main problem in the electricity sector. Most of the region's communities are supplied by off-grid thermal generation using diesel oil. The current Amazon energy matrix opens a large market for private investors in small- and medium-sized energy segments in the region, especially for decentralized alternative/renewable energy sources. The appeal of DE alternatives is further emphasized by the high transportation cost of diesel to isolated communities in the region. Table 4 illustrates the energy divide that plagues the state of Amazonas rural communities and Northern region of Brazil (Correa, 2001) [10, 28].

In addition, most of the diesel consumption is heavily subsidized by the federal government thus generating additional economic issues for the further economic development and growth of the region. Special taxes on energy households' bills from the rest of the country linked to the national energy grid finances the diesel consumption of the Amazon region [8].

The lack of energy results in lack of business opportunities in the rural communities of the state of Amazonas leading to massive migrations to the larger cities, such as Manaus. These migrations result in a number of social and economic maladies in these large urban centers.

The lack of energy has created a paradox: a region rich in natural resources is not able to generate wealth, leading to a cycle of poverty in the region. For instance, in the state of Amazonas, out of 4,600 communities, only 32 or 0.7% are connected to the regional electricity network. Moreover, 73% of the state of Amazonas rural properties does not have access to electricity. As a result, the interior is only accounting for 2% of the State's GDP [46, 24, 47].

Table 4: Electricity access, Amazon state, urban and rural households 2002. Coverage (%) in 2002.

	Urban	Rural	Total
State of Amazonas	97.8	27.2	85.4
Northern region	97.6	40.3	83.9
Brazil	98.8	73.2	96.0

Source: Ministerio de Minas & Energia, 2003.

In the last few years, several proposals to explore the hydro potential of the Brazilian Amazon region have been developed. The Madeira River Complex would transform the rivers' utilization in major 'corridors' for hydro power generation. This proposal calls for the construction of four dams, such as the Santo Antonio and Jirau in the state of Rondonia. These two dams will produce an expected 6,450 MW or the equivalent of 8% of Brazil's total energy supply. These projects would lead to the development of navigation locks, further advancing the use of riverways in the region. Another dam is also being proposed in the Amazon region: the Belo Monte dam. The Belo Monte dam will be the third largest in the world, located in the Xingu River, with an installed capacity of 11,233 MW [48].

The state of Amazonas has close to 3,000 energy generating units, potency varying from 12 to 66 KW. In addition, there is close to 1,000 energy generating units with generating capacity below 500 KW. However, a large number of these units are lacking parts and diesel fuel to run them. The lack of a dynamic entrepreneurial environment in the interior of the State makes these energy units too expensive to be maintained [20, 49].

The fate of the region's energy industry will largely determine the region's future economic growth and development potential. A large number of communities in the region still use firewood as fuel, leading to environmental degradation and pollution, in addition to low standards of living. Moreover, deforestation is a leading source of anthropogenic carbon dioxide emission. Furthermore, Brazil's nearly 2 million ha of deforestation, mostly in the Amazon region, amounts to 200 million tons of carbon [50, 51, 17, 52].

There are several business opportunities for carbon finance for the deployment of clean energy technologies in the Brazilian Amazon region. Carbon offsets are currently generating a demand for GHG Emission Reduction Units in the range of US $ 20 billion yearly. Brazil could benefit from investments by developed countries through the Clean Development Mechanism (CDM). For instance, diesel generators and its emissions provide good bases for Clean Energy Projects. One of the most efficient investment attraction strategies would be to generate emission reduction credits (ERCs) for CDM objectives, providing financial support for clean energy projects and technologies, such as biomass solutions, to replace aging and polluting diesel generators [42, 53, 54].

Recent discoveries of natural gas in the region are changing the regional energy matrix. The state of Amazonas has close to 100 billion m^3 of natural gas reserves, with a production of 5.5 million m^3/day. The gas pipeline connecting Coari to Manaus, 661 km long, the Urucu-Manaus pipeline, will generate 930 MW for the state of Amazonas. Natural gas is three times cheaper than diesel, which will facilitate the economic development of the region and will decentralize economic activities. The pipeline will only serve a limited number of communities in the region, leaving a large number of communities still heavily dependent on diesel generators [15].

Natural gas produced in the state of Amazonas offers a number of contributions to the sustainable development of Amazon region. The introduction of natural gas in the Amazon's energy matrix will lower local production costs and have a substantial positive impact on the local environment. Local energy costs are expected to drop by 60%. Natural gas can be used to power the local manufacturing industry located in the Manaus' Export Processing Zone (PIM), further reducing the region's dependence on diesel and reducing carbon footprint. Natural gas can also be used to power the local automotive and the shipping fleet. The adoption of hybrid engines (diesel/natural gas) will reduce shipping costs and allow production to reach markets at lower prices. In addition, natural gas can be used for cooking, refrigeration, and cooling systems, providing additional health and environmental benefits, such as reducing deforestation [20, 55].

Solar energy photovoltaics (PV) have a large potential in the Amazon region as well. Solar energy finds many uses in the region. The largest potential lies in the isolated communities where PV could

Table 5: Theoretical potential for power generation from biomass, Brazil and Amazon region.

Region	Technology/biomass	Theoretical potential (MWe)		
		Low yield	Medium	High
Amazon	Sugarcane	4	4	8
	Wood residues	103	137	205
	Agricultural residues	1,035	1,379	2,069
Brazil	Sugarcane	2,042	4,040	7,496
	Wood residues	431	574	859
	Agricultural residues	9,302	12,400	18,605

Source: Wade (2005).

be used to power houses, schools, and agricultural projects. Solar energy has been used to dry seeds, food crops, and other forest products, in isolated areas. For instance, solar dryers can be used to process Cupuaçu seeds, which have a very high commercial value, generating income to isolated communities in the region. Solar energy can also be used in powering refrigerators, helping local fishing communities to preserve their daily catches, allowing them extra days to sell their products in larger markets in the region. Local entrepreneurs have also developed small boats powered by solar power. For instance, the 'Seusui' and 'Voadeira Solar' boats can be used for commuting between communities in the region. [56–58].

Table 5 illustrates the potential of biomass as a source of energy for Brazil's Amazon region; agriculture residues show the greatest potential for the region. For instance, the Amazon region offers Brazil's greatest potential for the expansion of biodiesel in Brazil. The region has an ideal ecosystem for the expansion of plantations geared toward the production of biodiesel; buriti and macauba are good sources of biodiesel. The production of biodiesel creates jobs and generates income in the interior of the Amazon region, helping to curb deforestation and migration to cities like Manaus, in the state of Amazonas. Thermoelectric plants, generators, ship engines, and automobile engines could be outfitted to run on biodiesel. The Federal University of the state of Amazonas (UFAM) is also developing a biodiesel project in the city of Carauari. Law 11.097 of January 2005 allowed the use of biodiesel in Brazil's energy matrix. By 2013, it is expected that biodiesel will account for 5% of Brazil's energy matrix.

Residues of cocoa, Cupuaçu, acai, piquia, bacuri, and tucuma, abundant in the region, are also important inputs for biomass energy projects. Researchers from the Federal University of Amazonas, Center for Energy Research and Development (CDEAM) are developing a number of indigenous technology solutions for the region. Thermal gasification has been one of the technologies researched by CDEAM. This technology uses forest and agricultural residues, adding additional income and jobs to isolated communities. In addition, it provides a cleaner and sustainable energy matrix for these isolated communities [59].

Another energy option is related to free-flow hydro power turbines or hydrokinetic turbines. Brazil's hydro power is estimated at 260 GW. The Amazon region offers the country's greatest potential in using rivers to generate electricity. The vast distances and environmental concerns highlight the importance of looking at hydrokinetic turbines. This decentralized generation solution offers a number of benefits, such as low environmental impact, since it does not need artificial lakes

or dams. There has been several projects developed by local Brazilian research institutes and universities, but lack of funding has been the main obstacle for the further development of this decentralized solution for the Amazon region [60].

The Wind Power Atlas of Brazil (CEPEL) estimates that Brazil has a wind energy potential of 143,000 MWe. The Brazilian Amazon region offers a number of sites, such as Roraima, Amapa, and Para states, where wind energy could be harnessed, showing a potential of 12,800 MW (Ministerio de Minas e Energia, 2009). In the cities of Marapanim, Maracana, and in the Marajo Island in the state of Para, hybrids systems (wind/diesel) have been installed. These hybrid small-scale systems provide fossil fuel savings and have a positive impact on the local environment [61–73].

6 FINAL REMARKS

This paper has argued that the further integration of the Brazilian Amazon region in the Brazilian and global economies is inevitable. The business impact of this integration will be substantial. The diverse and vast amounts of resources found in the region will unleash a new cycle of business developments and opportunities for the Brazilian economy. A dynamic sustainable development strategy that stresses economic growth and development allied with conservation strategies offers the proper avenue to unleash the region's business potential. However, the increasing availability of energy in the region is a precondition for the further economic growth and development of its economic potential. But, the 'greening' of the Amazon's region energy matrix is a must in order to propel the region into a path of sustainability.

The development of clean/renewable sources of energy for the region will unleash a new cycle of economic development, leading to the creation of wealth and job vacancies in a region so impacted by poverty. However, it is also important to assess the environmental and social implications for all the energy solutions being proposed.

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