Renewable Energy in Brazil 2050

A vision for a totally renewable Brazil

EKOS BRASIL

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Executive summary

Could a country meet its own energy demands with its renewable sources? This question sounds utopic in the global energy scenario. However, Brazil can! Obviously, it cannot be achieved from one day to the next. Although the implementation of such an audacious plan is an enormous challenge, the required technologies and resources are already available.

Could Brazil meet its own energy demands in the future with only renewables?

Going 100% renewable can create great benefits to Brazil. The country could become a technological leader in the renewable energy and energy efficiency sectors. Energy prices would be less exposed to external market volatility. Brazil would significantly reduce its energy-related GHG emissions. Moreover, Brazil could export its fossil fuel resources, generating revenues, which could be invested in the country's development.

Great benefits for Brazil

Currently, around 50% of the energy produced in Brazil is from renewable sources, mainly from hydropower and biomass. The country is one of the world leaders, however, much more is possible! Instituto Ekos Brasil has carried out a projection of how Brazil could realize its vast renewable energy potential in order to meet its energy demand by 2050, exploring renewable energetic sources in an economic and environmental-friendly manner.

Brazil is already at the leading edge in the production of renewable energies

Taking into consideration the Brazilian government's forecast of population growth, Gross Domestic Product (GDP) and the influence of energy efficiency improvements, it is estimated that energy consumption (electricity and fuel) will increase from the current 3.200 terawatt hours (TWh) to 7.000 – 8.800 TWh by 2050. This study shows that Brazil has enough potential to supply its demand with renewable resources. Solar power and biomass are fundamental resources which, together, could meet 75% of future energy requirements.

Biomass and solar power could meet 75% of the energy demand of 8,800 TWh in 2050

The competitive agricultural sector already produces biomass for energetic purposes and shall become more efficient, without interfering in rainforest areas. The enormous amount of agroindustry residues could generate additional energy. Wind power, economically feasible even without governmental support, could be expanded with good wind conditions in Brazil. Also, hydropower still has interesting potential, however reduced due to environmental and social constraints.

Agriculture will be an even more crucial element of Brazilian energy production

The implementation of such vision is associated with great challenges. It is crucial to prepare the pathway as soon as possible. In order to achieve

Great challenges need long-term planning the number of required decentralized plants, a long-term installation plan is needed, as well as incentive programs.

Costs: annual investment in renewable energies of 115 billion dollars

An annual investment in renewable energies of 115 billion dollars is estimated based on available technologies at current values. This represents around 5% of the current GDP. However, compared to the 237 billion dollars that Petrobrás is planning to invest between 2013 and 2017, mainly in oil deposits at the pre-salt layer, the numbers sound reasonable.

The future energy matrix needs storage capacity and high efficiency transmission lines

The future energy matrix should take into consideration the seasonality of renewable sources, in order to build a solid energy supply in Brazil. Storage capacity, strong integration and the development of high efficiency transmission lines will be equally necessary.

Electricity will perform a central role and the transport system shall be adapted

The future energy matrix will set the consumption characteristics. Electricity will perform a central role and the transport system shall be adapted accordingly. Thus, Brazilian mobility by electric vehicles will be a relevant issue.

Politicians overlook the great potential of renewable energy

Unfortunately, the current energy policy in Brazil points in an opposite direction. The imminent electricity blackout, which is contingent upon the water supply, leads to thermal power generation, mainly supplied by fossil fuels, and the consideration of expanding nuclear power. On the other hand, investments in renewables decreased in the last years and the potential of bioenergy, solar and wind power remains overlooked.

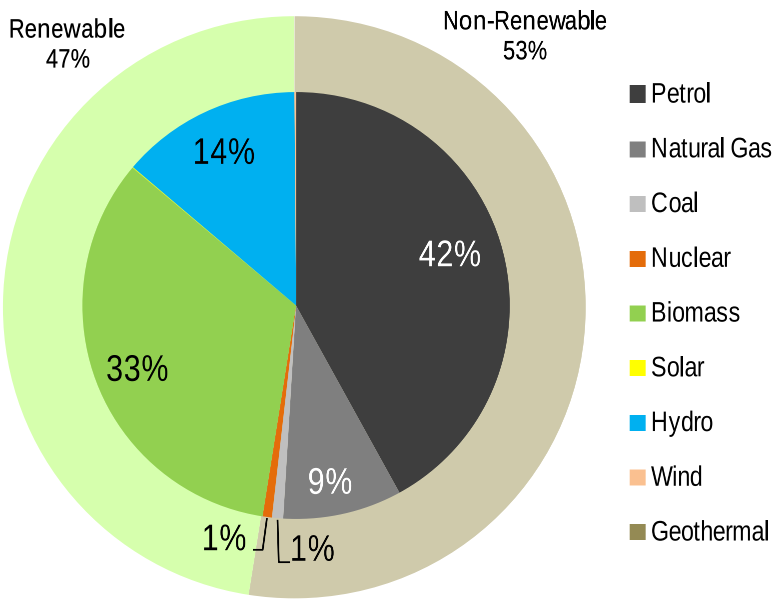
Contents

1 Introduction

Brazil is the Latin American country with the largest surface area and energy consumption. While 47% of the domestic energy supply in Brazil is provided by renewable resources, fossil fuels still dominate the energy mix (Fig. 1). In 2012, low water availability in hydropower plants led to increased production of energy through fossil fuel power plants. According to national government estimate, greenhouse gas (GHG) emissions related to energy consumption increased by 21,4% from 2005 to 2010, amounting around 400 Mio. t CO_2e (1).

Today, 47% of the energy produced is renewable

Fig. 1:
Domestic Energy Supply 2010



Source: Ministério de Minas e Energia, 2011. Illustration by Ekos Brasil.

Brazil is one of the global leaders in terms of renewable energy production. Considering its vast surface area[1] (8,5 million km^2) and natural resource availability, Brazil has the exceptional opportunity to become completely independent of non-renewable energy sources, turning into the emerging economic power with the lowest energy-related CO_2 emissions. In this scenario, its fossil fuels, rather than its renewable fuels, would be exported.

Brazil could become completely independent of non-renewable energy sources

[1] Brazil is the largest country in Latin America and the fifth-largest in the world by surface area.

Development of global energy-related CO_2 emissions

Estimates show that the global energy-related CO_2 emissions reached a record high in 2011 of 31,2 Gt CO_2e. A steady increase of renewable energy has cemented its position as an indispensable part of the global energy mix. The World Energy Outlook 2012 foresees that by 2035, renewable energy will account for almost one-third of total electricity output. However, fossil fuels will remain dominant in the global energy mix (2).

Energy shortages risk and discovery of the pre-salt leads to changes in the energy mix

While renewable energy is increasing its share within the global primary energy mix, Brazil is moving in the opposite direction encouraging fossil resources. The risk of electricity shortages led politicians to promote fossil fuel power plants. Moreover, the recently discovered deep-water pre-salt oilfield points towards a focus on oil production.

Climate change and energy security motivate the development of renewable energy

Climate change policies may lead to carbon pricing, which would change the competitive landscape of the global energy market and pose a relevant challenge to the production of carbon-based fuels. Renewable energy allows the country to reduce its dependency on non-renewable energy prices and supply. In Brazil conventional renewable energy sources, such as hydropower and ethanol, have already been explored and newer technologies may play an important role. However, in order to fully explore this potential it is necessary to mobilize private finance by providing an adequate public policy.

The main goal of this study: to encourage the discussion about the domestic renewable energy supply

The main goal of this study is to show that the renewable energy share in Brazil can be increased. We hope that this vision will encourage the discussion about the energy supply among relevant stakeholders (energy producers, energy suppliers, consumers) and government agencies. The purpose of this study is to determine whether Brazil has the necessary resources to supply the country's energy needs in 2050 exclusively by renewable energies and the most important challenges the country must face on the way.

Inspiration to other (developing) countries

If Brazil manages to become one of the greatest economic powers with nearly zero greenhouse gas (GHG) emissions related to energy consumption and completely independent from the import of fossil fuels, these achievements will serve as an inspiration to other (developing) countries.

2 General approach

The approach is based on three steps

The study is based on the following methodology.

- In the first step, the megatrends which have a major influence on energy production and consumption are described, including the development of population, economy, technologies, and costs up to 2050.
- In the second step, the future energy demand is defined based on GDP, population, growth, and energy intensity.
- In the third step, the potential of renewable energy in Brazil is calculated. The starting point is the theoretical renewable energy potential. The technical, ecological, and social restrictions are considered, reducing the potential (Fig. 2). It is further lessened by including the economic viability. Finally, existing and prospective competitive utilization is deducted to calculate the "feasible" potential, a realistic estimation of the additional renewable primary-energy potential for each energy source.

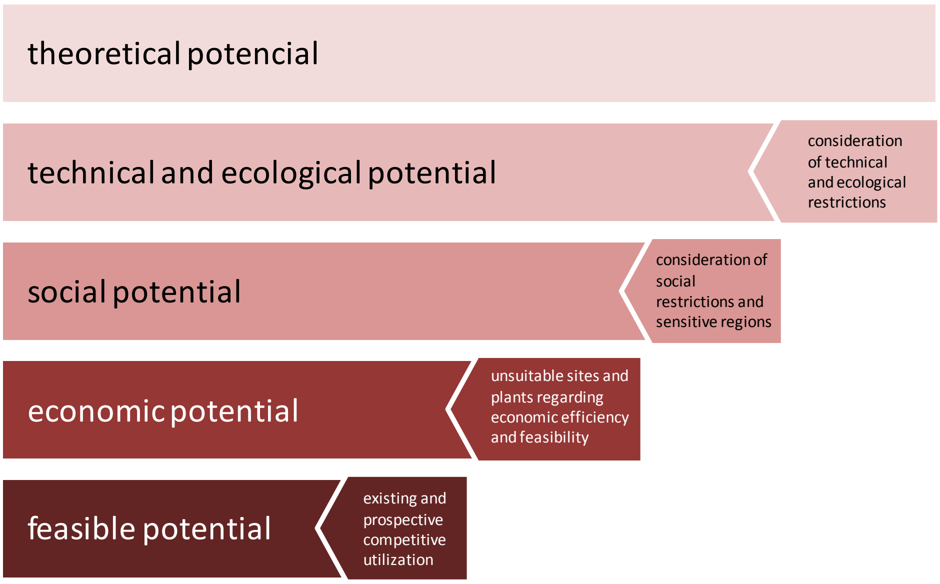


Fig. 2:
From theoretical to feasible potential

Reference systems define the energy output

In order to make the potential as graspable as possible, reference systems are defined. The result is the display of energies, such as electricity, bioethanol, biodiesel, and biomethane, expressed in watt-hours. The future energy production and the energy demand are then balanced and compared.

A renewable and independent energy mix will bring great challenges. The most important ones are named and addressed.

3 Trends

3.1 Brazil's economy

Directly connected to the population growth and also developments in different economic sectors, the GDP will roughly triple by 2050 with a strong growth of the services sector and a modest growth of the agricultural sector (see Appendix A1). This means a growth of services, a decrease of the industrial share and agricultural stability.

The GDP will roughly triple by 2050

The development of the industrial, services and agricultural sectors follows the trends in developed countries: The industrial sector experiences a downward trend due to declining participation in the economy and increased energy efficiency. On the other hand, the services sector's income will increase per capita. The main driving forces are the higher participation of the segment and consumerism (3). The agricultural sector in Brazil is powerful and will retain its position.

Services will increase, the agricultural sector remains powerful

The transportation sector is the main consumer of diesel in the country, responsible for almost 80% of the total diesel consumption. This will increase and become even more relevant because more and more vehicles will be on the market. Public policies might encourage rail or waterway transportation, especially for goods.

The transportation sector is the main consumer of diesel

3.2 Energy market

In the 1990s, Brazil has initiated a program of reforms of the power sector, including utility privatization and de-verticalization. Electricity generation and distribution started to account with private capital. Concessions for the construction of over 10.000 kilometres of transmission lines were encouraged and the reliability of the integrated grid has improved (4). Free electricity purchase is limited to large consumers.

The power, oil and gas sectors have been liberalised and started to receive private capital, since 1990s and 2000s.

Since 2000, the oil and gas upstream sector has been liberalised and started to receive private investments.

Rather low policy targets (by 2020) for wind, biomass and small hydropower were introduced. The national government has a target to keep energy-related CO2 emissions below 680 Mio t CO_2e by 2020 t CO2e, which means having an economic carbon intensity by 2020 similar to

Low policy targets for renewable energy development

2005. There are no targets for renewable energy development. Brazil relies on capacity tenders to increase its electricity generation base. As the price competition has been favouring the development of conventional power sources, Brazil is considering having specific tenders for each energy source. In 2011, Brazil had a new round of competitive tender for 20-year contracts for wind and biomass power projects and 30 years for hydropower.

Encouraging biofuels

In addition, there are mandated biofuel blends for sugar cane ethanol (E18-25) and biodiesel (B5). In 2011, the ethanol blend level was reduced from 24% to 20%. The government announced financing and loans for companies to increase yields and to encourage further investments (5).

Brazilian energy policy and energy strategy

Energy and environmental laws are very complex: obtaining licenses and fighting legal challenges routinely adds years to schedules and millions to budgets. The energy ministry decides on which projects to approve for implementation. The environment ministry is responsible for the environmental aspects. The national energy plan for 2030 proposes a relatively broad basis for the country's energy outlook. However, it does not consider the great potential of photovoltaic. The reflections on the potentials are not transformed in any way into a national energy strategy with specific targets and measures for implementation.

3.3 Technologies and costs

Available technologies in general become more efficient

The pace of technological innovation and deployment significantly affects the efficiency of production, the use and supply of energy, as well as the costs. This study assumed that available technologies, in general, will become more efficient, thus lowering the cost of energy production.

New technologies are expected, such as second-generation ethanol

The technologies for the production of energy from biomass are already consolidated. Therefore, no major technological developments are expected, except for new technologies, such as second-generation ethanol[2] production or solar-powered gasification[3]. Rather, costs are expected to decrease. Wind energy technology, which is already used economically in some regions of Brazil, is mature and the cost will decrease further. The steepest path on cost reduction is expected in the field of

[2] Production of ethanol from biomass, mainly from sugar cane bagasse.
[3] Biomass gasification increased by solar power.

solar energy. If the demand for solar power massively increases worldwide as projected, the production costs of the panels will decrease even further. Solar energy is not too far away from being competitive today. Nowadays, hydropower is the cheapest renewable energy source in Brazil. However, a cost increase is expected in the future, since sites with the highest energy efficiency are already in use, and new locations will involve complex building projects and high investment in environmental protection measures.

3.4 Influence of the pre-salt

Conservative estimates for the pre-salt oil indicate 50 billion barrels

In 2007, the oilfields of the pre-salt were announced in Brazil. Before pre-salt, the proven and probable amounts of the county's oil reserves were approximately 20 billion barrels. Conservative estimates for the pre-salt oil indicate 50 billion barrels, which is a little less than the total reserves in the North Sea.

Developing the pre-salt could cost 1 trillion dollars

Since the pre-salt oilfields were discovered, Brazil's politicians have neglected reforms in the renewable energy sector. With this prospective amount of an available energy resource, the future challenge of supplying the energy demand of the country seems to be solved. However, extraction of the pre-salt oil is an extraordinary technical challenge (great depth, high pressure, new seismic techniques), and is linked to high costs: Developing the pre-salt could cost 1 trillion dollars, which is about half of Brazil's 2010 GDP (6). This may be an opportunity for renewable energies.

4 Energy consumption 2050

Total Final Energy Consumption

Brazilian population will stabilize after 2040

For the coming years, the Brazilian population is expected to continue growing, but at a much less rapid pace. According to the Instituto Brasileiro de Geografia e Estatística (IBGE), the Brazilian population will stabilize or even decrease slightly after 2040. In 2050, the population is estimated to reach 215 million people (7).

The per capita demand of final energy in Brazil will grow

Nowadays, the per capita demand of final energy in Brazil is still quite low compared to developed countries[4]. In 2010, the consumption of end energy was between 1,1 and 1,3 tons of oil equivalents (TOE) per capita, and the final energy demand amounted to 254 million TOE or roughly 3.000 TWh (8). From 2010 to 2050, the GDP was set by huge growth from 2.200 dollars per person up to $7.700 dollars in the "optimistic energy consumption" scenario, or as much as 9.000 dollars in the "average energy consumption" scenario. Also, the energy intensity per TOE will decrease by 30% in this period, following the world average path (8).

Final energy demand in 2050 will be between 7,000 and 8,800 TWh

The modelling of the development of the final energy demand (Fig. 3) in this study (relative to population growth, energy intensity development and GDP) estimates it multiplying roughly by the factor of 2,4 ("optimistic") or 2,9 ("average") to a final energy demand in 2050 of 600 million TOE or 7.000 TWh ("optimistic") or 769 million TOE and 8.800 TWh ("average"). For more information about the modelling, see Appendix A1.

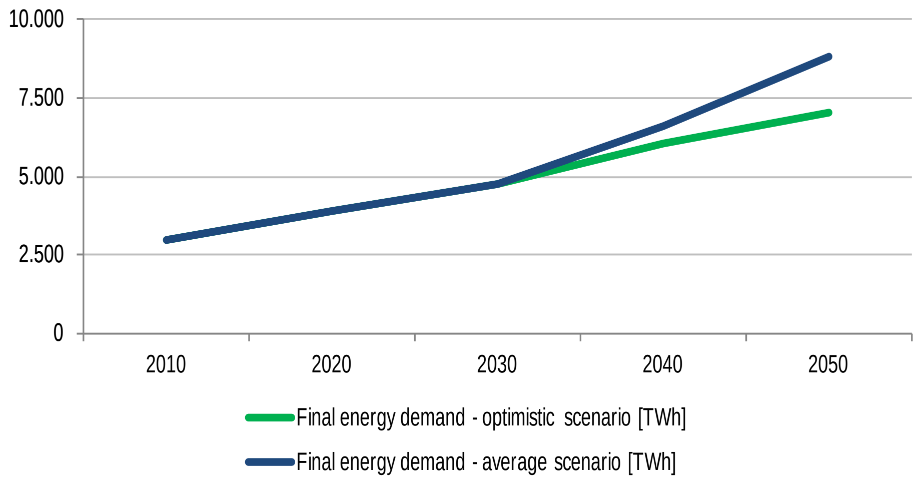


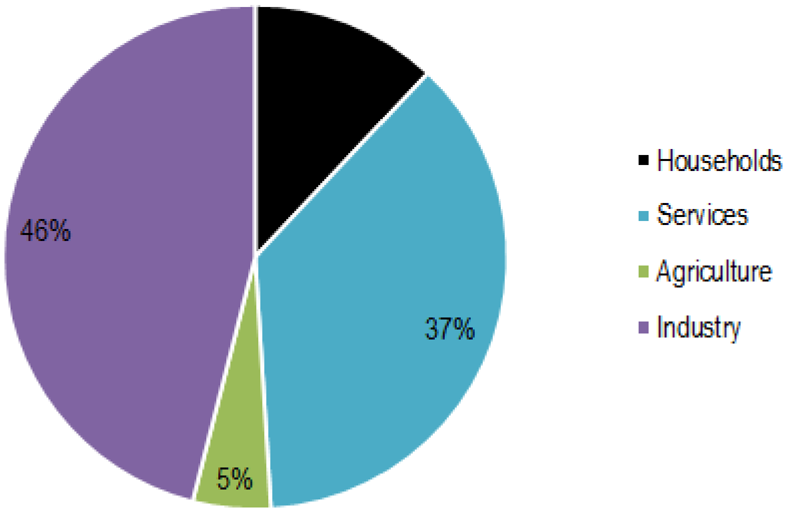
Fig. 3:
Development of the final energy demand from 2010 until 2050

[4] Consumption of end energy in Brazil 2010 lies between 1,1-1,3 TOE per capita; Switzerland roughly 2,8 TOE per capita; OECD countries 4,3 TOE per capita; USA 7,0 TOE per capita (9), (41), (42).

Energy consumption of the economic sectors

Overall energy consumption is based heavily on the industrial and services sector (Fig. 4). In 2010, Brazilian industry consumed about 46% of the final energy and the services sector around 37%. Brazilian households consumed 12% of the final energy and the agricultural sector 5%.

Fig. 4:
Energy consumption by economic sector



The energy consumption in the services sector will expand

It was assumed that the energy consumption of the industry and services sectors follows the development trends of the GDP and population (see Section 3.1). The energy consumption in the services sector will expand, while consumption in the industry sector will decrease, and the consumption in the households sector will probably stabilize because of two opposing effects: efficiency and higher electrification of the households (more electronic and electrical devices) (9).

5 Renewable energy potential by 2050

Section 5.1 provides an overview of the results according to the renewable energy potential for 2050. The following chapters briefly describe each type of energy source and the main assumptions and restrictions. For more information about the calculations and the modelling, please see Appendices A2 and A3.

5.1 Overview

Feasible renewable energy potential

Table 1 shows the feasible energy potential for the year 2050 by energy sources. There are roughly 12.600 TWh of energy included in the available resources regarding environmental, economic, and social restrictions[5].

Table 1:
Feasible energy potential

Energy Resources	Potential 2050 [TWh]
Biomass	5.000
Energetic Crops	*1.171*
Agriculture biomass residues	*2.006*
Agroindustrial biomass residues	*1.694*
Urban residues and sewage	*46*
Manure	*79*
Algae	*3*
Solar	5.220
Photovoltaic	*4.950*
Thermal	*270*
Hydro	962
Hydropower	*882*
Tides and Waves	*80*
Wind	1.388
Geothermal	1
Total	12.571

5 Note that the amount of 12.571 TWh is not equal to the final energy output. The final energy output results from the conversion of the energy included in the resources in different types of plants, with consideration of capacity factors, efficiency factors, and losses.

The achievable energy potential for 2050 is based on the available energy sources distributed in different types of power plants, where the energy source is converted into energy products, such as fuels, heat, and electricity.

Available energy potential

The energy potential for 2050 amounts to 8.270 TWh (Table 2). This value considers energy produced by reference plants, based on the energy sources.

Table 2:
Available energy potential for 2050

Available Energy Potential 2050	[TWh]
Biomass	3.213
Ethanol	532
Biodiesel	280
Biogas	146
Gasification	215
Incineration	1.718
Charcoal / Pellets	320
Biokerosene	2.80
Solar	3.084
PV integrated in buildings	1.080
Solar heat plant in buildings	480
PV open-field	1.524
Hydro	932
Small hydropower	92
Large hydropower	840
Tidal Power	0.06
Wind	1.040
Small wind park	260
Large wind park	780
Geothermal	0,80
Total	8.270

This number shows that the energy demand projected for 2050 of 7.000 to 8.800 TWh could be ensured by 90% to 100% by renewable energies.

Biomass and solar power play a crucial role: together they would cover more than 75% of the supply matrix (Fig. 5). The current GHG-emissions of about 400 Mio t CO_2e from fossil energy consumption would be reduced to zero (1).

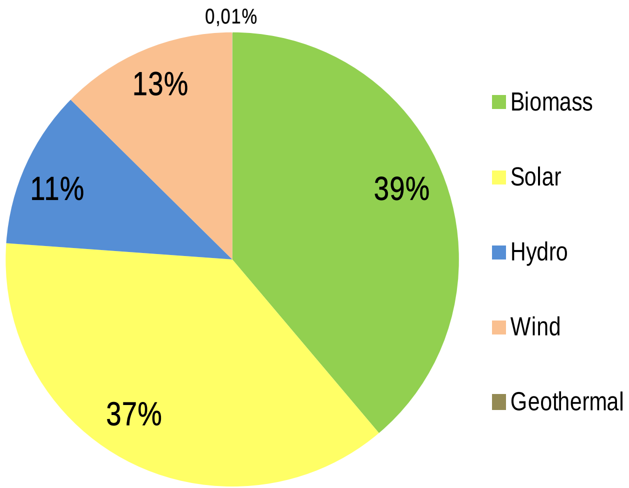


Fig. 5:
Energy production in 2050

It is important to highlight that Brazil has all the necessary resources to establish independent solar production, based on the silicon value chain.

Brazil is capable of establishing an independent solar production

Solar power in Brazil

Solar power in Brazil is strongly focused on hot water production. The Brazilian market has been rapidly expanding due in part to programs such as "Minha Casa - Minha Vida." Brazil's installed capacity is the fifth largest in the world. Solar power potential is vast: the lowest solar radiation on Brazil's surface is still higher than the highest solar radiation on Germany's or Switzerland's. Furthermore, Brazil has all the necessary resources to build the entire value chain, from mining to solar cell production up to solar plant installation and electricity generation. Solar power systems, especially those integrated in buildings, bring the advantages of easy installation and maintenance, and the electricity is produced decentralized and consumed locally. Nevertheless, solar electricity production is barely ever mentioned in the national energy plan for 2030 (3), (5).

The highly competitive agricultural sector already produces biomass for energetic purposes and can become more efficient, without interfering with the natural forest areas. In addition, enormous amounts of agricultural and agro-industrial residues can be used for energy production without any environmental or social risks.

Biomass: high potential of agro-industrial wastes

Wind energy has already reached economic production even without the government's support. This has the potential to expand with good wind conditions in Brazil.

Wind has already reached economic production

Hydro energy potential is already well used

The feasible potential of hydropower with no severe impact has already been explored, and an interesting potential is available, but will be subject to environmental and social restrictions.

Little potential for geothermal energy

Geothermal potential is not very attractive in Brazil since the country is not located in geothermal anomalies. However, some south and southeast regions can explore the geothermal gradient for local water heating and heating pumps. Nowadays, geothermal energy is primarily used for aquatic recreation (10).

Final energy output

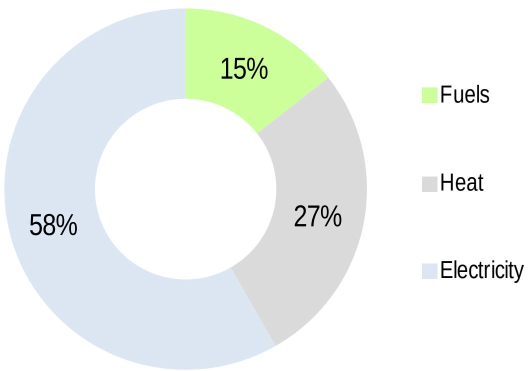
The energy potential for 2050 amounts to 8.270 TWh. Deducting transmission losses between the plants and consumers, the final energy output is 8.024 TWh, in terms of fuels, heat, and electricity (Table 3).

Table 3:
Final energy output in 2050

2050 Energy type	Available Energy Potential [TWh]	Final Energy Output [TWh]
Fuels	1.157	1.157
Heat	2.192	2.192
Electricity	4.921	4.675
TOTAL	8.270	8.024

It is expected that the current electricity transmission losses of 14% (11) could reach 5%, considering the transmission developments and improvements until 2050.

Fig. 6:
Final energy output in 2050



The final energy output is based predominantly on electricity

The final energy output (Fig. 6) is based predominantly on electricity (58%). Transport fuels would account for only 15% in the future energy matrix. Thus, the economic system, especially the transport sector, may change and adapt to the large offer of electric energy. Powerful grids, storage capacities, and an intelligent integration of power plants are needed.

Energy production areas

Figure 7 gives a rough overview of the most important regions for future energy production (see Appendix A6).

Fig. 7: Energy production areas

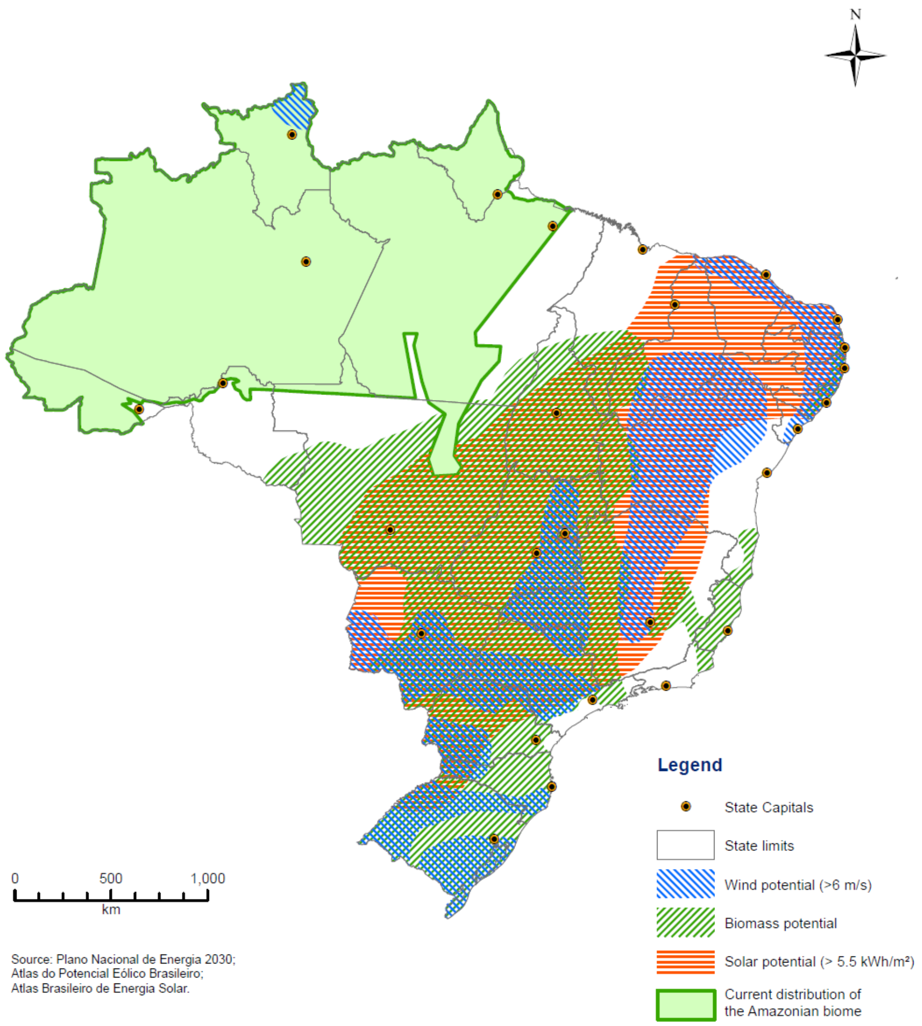


Illustration by Ekos Brasil.

Solar power can be largely produced above all in the North-eastern part of Brazil (low environmental impacts) and large urban areas.

Energy from biomass can be produced close to the great agricultural and agro-industrial areas of Brazil, in the Southern, South-eastern, and Mid-western regions of the country.

Wind power shows the greatest potential on the northeast coast and also in the south, southeast and the central part of the northeast.

5.2 Biomass energy

5.2.1 Energy crops

Theoretical Potential	**1.171 TWh**

Main assumptions

- Sugar cane products (ethanol, bagasse, straw), oil plants (e.g., jatropha, soy), and wood are considered.
- The potential is based on the Brazilian energy plan for 2030 (12). The growth rate assumed for sugar cane and oil plants between 2030 and 2050 is 2% per year, an additional increase of 50%. The one for wood was assumed equal to 10%.
- The Brazilian energy plan for 2030 presents the energy crops' potentials as final products, such as ethanol and the energy amount from biomass. Thus, it was considered that 100% of the theoretical potential can be used and converted into the feasible potential for energy crops.

Main challenges and restrictions

- Environment: Only areas that do not compete with native forests or valuable agricultural land can be considered for plantation.
- Technology: By consolidating technology, the efficiency will increase.
- Economy: The energy production from wood is economically not very interesting. The wood takes a longer time to grow than sugar cane, for example, depending on the regional characteristics.
- Social: The sugar cane industry is very important in Brazil, the acceptance is good; however, it is necessary to reduce the firing-harvest practices in some regions.

Feasible Potential	**1.171 TWh**

Reference plants

- Ethanol plant first generation
- Biodiesel plants
- Incineration
- Charcoal
- Pellets

For more information about the plants, see Appendix A4.

5.2.2 Agricultural residues

Theoretical Potential	**8.025 TWh**

Main assumptions

- Agricultural residues of soy, corn, sugar cane (straw,) and rice (straw) production.
- The potential for 2030 is based on the 2030 energy plan for biomass (12). The growth rate assumed for agriculture between 2030 and 2050 is 50%.
- Agricultural residues are mostly unused today. During harvest, straw and other parts are not collected.
- In 2050, it is assumed that 25% of the residues will be collected and used for energy production (collection means an additional step in the production chain).

Main challenges and restrictions

- Environment: No additional land is necessary; use of residues, which are currently left on the field or burnt (e.g., sugar cane production).
- Technology: Consolidated technology, the challenge will be the inclusion of the collection process.
- Economy: The additional collection process makes energy production costs rise.
- Social: No social restrictions.

Feasible Potential	**2.006 TWh**

Reference plants

- Ethanol plant second generation
- Biogas plants
- Gasification
- Solar-powered gasification
- Incineration

For more information about the plants, see Appendix A4.

5.2.3 Agro-industrial residues

Theoretical Potential	**1.710 TWh**

Main assumptions

- There is a great variety of agro-industrial residues, depending on the type of agroindustry. The potential of the following types of residues are considered: bagasse (sugar cane and citrus), black liquor (from paper industry), wood residues, barks (coconut, coffee, cocoa).
- The potential is based on the 2030 energy plan for biomass (12). The growth rate assumed for agroindustrial residues between 2030 and 2050 is 50%. The one for black liquor was assumed equal to 10%.
- The availability of the agroindustrial residues is much better than the agricultural residues because they are already part of an industrial process and no additional collection is required.
- The theoretical potential of sugar cane bagasse, black liquor, and wood residues can be realized completely (100%).
- The theoretical potential of citrus fruit bagasse can only be used up to 50%, because this biomass is partially used for animal feed. Also, the existing markets are very small, which makes an additional energy production process unworthy.

Main challenges and restrictions

- Environment: Positive effects because of the use of residues.
- Technology: Consolidated technology and developing technology (solar gasification); the biomass is easily available.
- Economy: No challenges.
- Social: No social restrictions.

Feasible Potential	**1.694 TWh**

Reference plants

- Ethanol plant second generation
- Biogas plants
- Gasification
- Solar-powered gasification
- Incineration
- Charcoal/Pellets

For more information about the plants, see Appendix A4.

5.2.4 Biogenic municipal solid waste

Theoretical Potential	88 TWh

Main assumptions
- The potential is based on the 2030 energy plan for biomass (12). For 2050, an additional increase of 20% over the 2030 potential is considered, mainly due to more residue generation per capita. From 2030 to 2050, a decrease in population is predicted (7).
- The municipal solid waste contains different types of residues (e.g., plastics, paper, glass, organic material, etc.). The energy plan for biomass assumes that almost 50% of residues is organic material.
- Currently, municipal solid waste is almost entirely disposed of in landfills. New policies aim to promote separation and recycling. We assume a 50% use of the theoretical potential energy content in the organic waste.
- Volume of municipal solid waste in 2030: 92 million tons; 2050: 111 million tons (3).
- The organic material represents almost 50% of the waste volume with a medium energy content of 1.8 MWh/t of organic material (13).
- Technological advances are needed.

Main challenges and restrictions
- Environment: Positive effects because of the use of residues.
- Technology: Consolidated technology but rarely implemented in Brazil; the greatest challenge is the flue gas purification and garbage segregation.
- Economy: High initial investments needed, the technology is expensive.
- Social: No social restrictions.

Feasible Potential	44 TWh

Reference plants
- Biogas plants
- Incineration

For more information about the plants, see Appendix A4.

5.2.5 Urban sewage

Theoretical Potential	23 TWh

Main assumptions

- Sewage sludge is a residue of the wastewater treatment process.
- The sewage sludge contains 16 kg BOD per capita and year, which results in 100 kWh per capita and year methane (14).
- In 2050, only 10% of the theoretical energy content is usable, because of the high dilution challenges and the high initial investments.

Main challenges and restrictions

- Environment: Positive effects because of the use of wastewater.
- Technology: Consolidated technology but rarely implemented in Brazil; the greatest challenge is the low energy density of the sludge (water content > 97%).
- Economy: High initial investments needed.
- Social: No social restrictions.

Feasible Potential	2,3 TWh

Reference plants

- Biogas plants

For more information about the plants, see Appendix A4.

5.2.6 Manure

Theoretical Potential	567 TWh

Main assumptions

- The study considers bovine, swine, and poultry manure (15).
- Bovine: Number of bovines in 2010: 209 million; for 2050, 50% increase: 314 million. Bovine produce 30 kg manure/day with a methane potential of 15 litres CH_4/kg manure. In 2010, 31 million bovines were slaughtered. For 2050, 50% increase: 46 million bovines to be slaughtered, the use of slaughterhouse waste results in 4.3 m^3 CH_4/killed bovine (15) (16) (17).
- Swine: Number of hogs in 2010: 38 million; 2050: 58 million. Hogs produce 13 kg manure/day with a methane potential of 10 litres CH_4/kg manure.
- Poultry, meat production: Number of chickens in 2010: 1,000 million. For 2050, 50% increase: 1.540 million. Manure generation of 0,05 kg manure/day with a methane potential of 80 litres CH_4/kg manure.
- Poultry, egg production: Number of chickens in 2010: 210 million; 2050: 316 million. Manure generation 0,1 kg manure/day with a methane content of 39 litres CH_4/kg manure.
- The feasible potential for bovine corresponds to only 10% of the theoretical potential, because of the long time spent in pasture. Livestock breeding of swine and poultry is more concentrated; thus, 50% of the potential is assumed as feasible.

Main challenges and restrictions

- Environment: Positive effects because of the energetic use of manure. Also, the stabilization of manure permits its application as fertilizer in the end.
- Technology: Consolidated technology, but rarely implemented in Brazil; the main challenge is the collection of the manure.
- Economy: High initial investments needed.
- Social: No social restrictions because it is mainly implemented in sparsely inhabited regions.

Feasible Potential	79 TWh

Reference plants

- Biogas plants

For more information about the plants, see Appendix A4.

5.2.7 Algae

Theoretical Potential	**32 TWh**

Main assumptions

- Energy production technology from algae in complementation with sugar cane production is considered (18).
- It is assumed that two additional litres of biofuel can be produced per ton of sugar cane in the ethanol industry, using vinasse (residual liquid from ethanol distillation) and CO_2 from sugar fermentation (18).
- Only 10% of the theoretical potential was considered feasible based on the total ethanol production for 2050, because of the great challenges this technology faces.
- Another possibility would be the production of algae in open ponds on semiarid lands with salty water (no competition for food production or native wood). This additional potential is not considered in this study.

Main challenges and restrictions

- Environment: Positive effects, because the sugar cane vinasse can be used for the algae production, and still be used as a fertilizer and for irrigation afterwards.
- Technology: New technology with only a few pilot plants; experts see different applications.
- Economy: Economically not yet interesting, high investments to be made.
- Social: No social restrictions.

Feasible Potential	**3.2 TWh**

Reference plants

- Biokerosene plants

For more information about the plants, see Appendix A4.

5.3 Solar power

Theoretical Potential	**522.000 TWh**

Main assumptions

- Solar power panels on buildings and open-field photovoltaic plants are considered. Solar thermal plants are considered only on buildings in urban areas.
- The total area in Brazil for pastures and agriculture is 366 million hectares. This study assumes 1% of this area could be used for photovoltaic plants, mainly in the northeast, without affecting food production or other energy technologies.
- Currently, the efficiency factor of solar panels is approximately 15%. For 2050, it is considered that the efficiency will increase to 25%.
- The solar radiation values were obtained for five reference cities, one per region in Brazil: Manaus/AM - North, Petrolina/PE - Northeast, Cuiabá/MT – Middle West, Belo Horizonte/MG - Southeast and Florianópolis/SC - South (19).
- An average ratio 0,5 was assumed between panel surface and land surface (2 m^2 land needed for 1 m^2 panel). It is important to note that in the South this ratio is 0,2 because of the angle of incidence of the sun's radiation.
- A capacity factor of 1.800 hours/year was considered for energy production.

Main challenges and restrictions

- Environment: The area used for solar power production must not conflict with other uses (e.g., food production) or create environmental issues.
- Technology: The main challenge is the low efficiency of the panels and the energy storage.
- Economy: Prices are decreasing; solar power will soon be competitive; China controls the world market of solar panel production with very cheap panels.
- Social: The acceptance of solar power is generally good, but unknown for solar parks.

Feasible Potential	**5.220 TWh**

Reference plants

- PV integrated in buildings
- Solar heat plants integrated in buildings
- PV open-field (solar park)
- Concentrated solar power plants

For more information about the plants, see Appendix A4.

5.4 Hydropower

Theoretical Potential	**1.860 TWh**

Main assumptions

- Energy production of hydropower in dams and rivers is already wide spread in Brazil. The remaining potential is good but depends on environmental restrictions.
- Energy production of tides and waves is not yet a consolidated technology, but is considered in the study (20).
- We assume that the potential for 2050 does not vary from the potential of 2030 calculated in the national energy plan (9). The national energy plan already considers environmental restrictions.
- A capacity factor of 5.600 hours/year was considered for energy production, based on latest year's statistics (21).

Main challenges and restrictions

- Environment: Huge impacts exist on the natural riverbed and its surroundings, fish migration, relocation of the population because of flooding, et cetera; therefore, national parks, indigenous reserves, and very populated areas are excluded from the study.
- Technology: Consolidated technology (except for tides and waves).
- Economy: Lowest price for renewable energy technology, but hydropower becomes more expensive due to new technologies (river flow power turbines without a storage system), challenging constructions, higher investments for environmental offsetting, and areas with lower energy potential.
- Social: Low acceptance in certain areas, conflicts in Amazon.

Feasible Potential	**962 TWh**

Reference plants

- Hydropower plants
- Tidal power plants

For more information about the plants, see Appendix A4.

5.5 Wind energy

Theoretical Potential	**3.470 TWh**

Main assumptions

- This study considers the declared potential from the energy ministry (22).
- Water areas are excluded.
- Up to 2050, 40% of the theoretical potential was assumed as feasible. This corresponds roughly to the potential from wind velocities of ≥ 6.5 m/s on 50 m height over ground.
- A capacity factor of 2.600 hours/year was considered for energy production, based on latest year's statistics (21).

Main challenges and restrictions

- Environment: Visual impact, other impacts are not yet entirely evaluated (bird kills, noise, etc.).
- Technology: Consolidated technology; after hydropower lowest price for renewable energy technology.
- Economy: High initial investment.
- Social: Environmental impacts can be a challenge for plant's acceptance.

Feasible Potential	**1.388 TWh**

Reference plants

- Wind parks

For more information about the plants, see Appendix A4.

5.6 Geothermal energy

Theoretical Potential	**2,4 TWh**

Main Assumptions

- The geological atlas of Brazil reflects a feasible potential of 300 MW of thermal energy (23).
- For 2050, it was assumed that 25% of the potential will be realized.

Main challenges and restrictions

- Environment: The effects and risks are mostly unknown.
- Technology: Not yet a consolidated technology, but in principle no technical barriers.
- Economy: Expensive technology and high initial investment costs.
- Social: Unknown.

Feasible Potential	**0,6 TWh**

Reference plants

- Geothermal heat pump

For more information about the plants, see Appendix A4.

6 Challenges

6.1 Costs and financing

An annual investment of 115 billion dollars is needed for a full renewable matrix

Most of the renewable energy potential is related to unconventional capital-intensive technologies, which differ from conventional sources, such as hydro and thermal plants, and pose a challenge in terms of capital cost. In order to achieve the installed capacity of 2.040 GW, approximately 4.400 billion dollars should be invested by 2050, which roughly represents an annual investment of approximately 115 billion dollars (see A5 for details). In order to achieve this, private financing must be attracted through the smart use of limited public finance and effective public policy (24).

Different investment strategies

According to the Energy Expansion Plan (25), a total energy investment of 500 billion dollars during 2012–2021, or an annual investment of 50 billion dollars, which represents 2.2% of the GDP (2012), is necessary. An annual investment of 115 billion dollars for a fully renewable energy production represents approximately 5% of the current GDP and 1.5% of the GDP in 2050. Therefore, in order to harmonize the needed investment according to its representativeness of the GDP, two different strategies have been elaborated (see Fig. 6):

i. Allocating the current energy investment level (2.2% of GDP) in renewable-related investments by 2030, and then increasing the investment share of the GDP by 2.7% annually until an investment of 3.5% of the GDP is reached by 2050; or
ii. Allocating the current energy investment level (2.2% of GDP) in renewable-related investments by 2020, and then increasing investment share of GDP at 1% annually until an investment of 2.8% of the GDP is reached by 2050.

GHG emission reductions achieved may be used as an instrument to raise capital to renewable sources, for instance through the Green Climate Fund (26).

Renewable investments as a percentage of GDP

As illustrated in the figure 6, increasing investments in renewable energy already in the next decade is crucial to avoid that the capital requirements for a fully renewable energy mix exceed the current energy investment level.

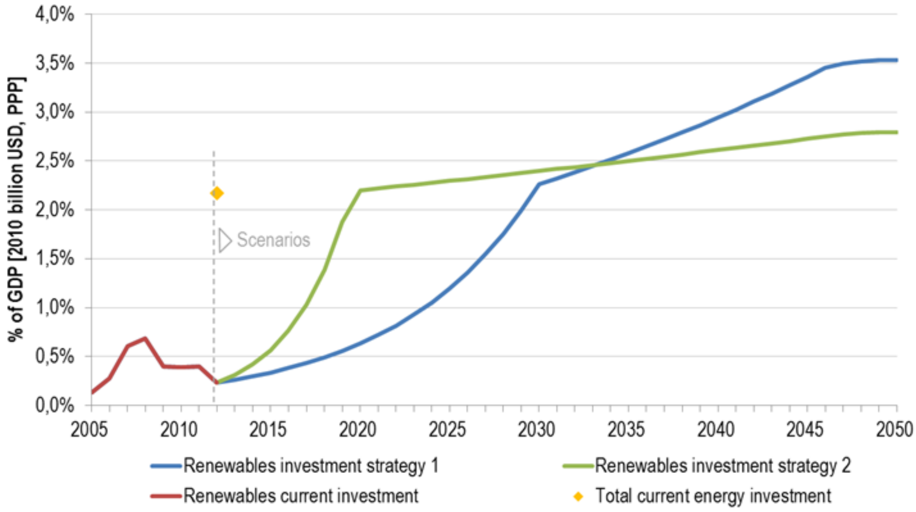


Fig. 6: Consequences of the investment strategies

Approximately 90% of the investments should be allocated to solar and wind plants

Approximately 90% of the investments should be allocated to solar (65%) and wind (25%) plants, even though they jointly represent only 50% of the energy output (Fig. 7). Their higher initial cost may be overcome by public incentives that internalize part of the positive externalities of renewable power generation.

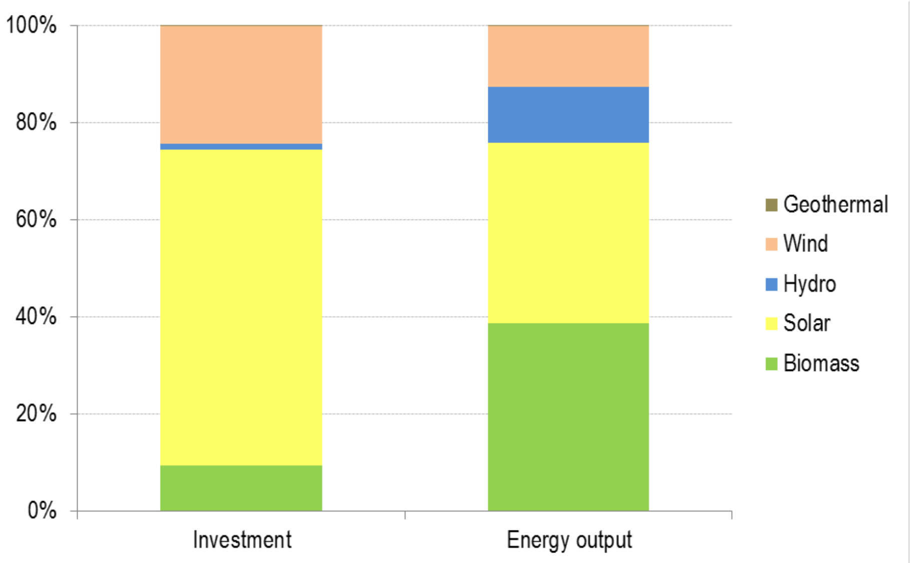


Fig. 7: Total needed investment versus energy output by 2050

Hydro and Biomass are most competitive in the short term

Hydropower presents the lowest capital cost followed by biomass plants. These technologies may represent the most competitive in the short term. However, an in-depth case-by-case due diligence must be conducted in order to prove their feasibility.

Other Investments

Also great investments have to be made in transmission lines and in the resolution of environmental issues caused by the construction of large dams and pipelines (2).

According to REN21, by 2013, 127 countries will have developed policies aimed at increasing the deployment of renewable energy technologies. Instruments such as feed-in tariffs, which guarantee a fixed price for renewables, renewable portfolio standards, which push utilities to increase renewable shares on their portfolios, energy green labels, which promote a premium price for renewables by differentiating them from conventional sources, and fiscal incentives on investments, sales, or public financing, have been widely adopted.

Incentives for renewables: experiences in more than 120 countries

Subsidies to fossil fuel led to energy cost increase

According to the International Energy Agency (IEA), worldwide subsidies for fossil fuel consumption amounted to an estimated 523 billion dollars in 2011, an increase of 27% over 2010 — reflecting rising energy prices and increased consumption of subsidised fuels. In Brazil, the number of fossil fuel power plants increased by 125% in the last decade, reaching an installed capacity of 23.5 TW. The promotion of thermal plants was aimed at reducing the dependency on hydroelectricity; however, the energy cost of these fossil fuel plants has risen to 400 dollars/MWh.

6.2 Energy storage and transmission

The production of renewable energies fluctuates. There are seasonal (summer/winter, wet/dry season) as well as daily fluctuations (day/night, morning/evening/midday), which the grid operator has to contend with.

Daily and seasonal fluctuations

To counterbalance short fluctuations on a daily basis, an intelligent combination of power plants has to be chosen. Biomass is a short- to mid-term storable resource and can produce a base load of a certain amount of energy on demand. Thus, resources like solar and wind power should be added and combined.

Intelligent combination of power plants

To counterbalance seasonal/long-term fluctuations, bigger storage capacities are needed. Pumped storage power plants offer a solution, preferably installed in mountainous regions. This may require intergovernmental cooperation and the development of strong grids.

Bigger storage capacities are needed

Transmitting energy over great distances always involves transmission losses. These are especially high in the electricity grid. Currently, approximately 14% of the electricity produced is lost on its way to the final consumer (11). Decentralized energy production nearer to the final consumer shortens transmission distances, and becomes more and more

Transmission losses will decrease in the future important. Losses will decrease in the future assuming a renewed and improved electricity grid.

Mismatched location of energy production and demand

It is foreseeable that international energy trade will grow steadily in the evaluated timeframe to accommodate the increasing mismatch between the location of energy production and energy demand (e.g., the great distances between Brazil's hydropower facilities and the main demand centers requires high investments in transmission infrastructure and is accompanied by high distribution losses). Therefore, sufficient investment especially in the energy-supply infrastructure is needed worldwide (2).

6.3 Electrification

The Brazilian economy must find ways to adapt itself to an electricity-based energy matrix

The future energy matrix is largely based on electricity. The Brazilian economy must find ways to adapt itself to this new energy supply. The government can support the developments by introducing corresponding incentives for the economy to jump on the bandwagon, figuratively. Especially the public and private transport sectors have to make significant changes. Electric mobility and the shifting from road to rail can be solutions.

Two key challenges: transmission capacity and smart grid

Integrating a substantial amount of renewable energy sources into the electricity markets presents two key challenges: transmission capacity and a smart(er) grid.

The electricity system must be able to manage the intermittency of renewable energy sources

Regulatory mechanisms must support the construction of an appropriate transmission infrastructure. Often renewable resource potential is located far from population centers. The ability to site and finance adequate transmission lines to interconnect renewable generation to the grid is key to the expansion of renewable energy. Also, the electricity system must be able to manage the intermittency of renewable energy sources, such as wind and solar, which cannot be turned on and off like fossil fuel power plants. An adequate transmission infrastructure helps in managing intermittency but is not sufficient.

Smart grids will help to integrate renewable energies into the grid

Second, any electricity market with a significant fraction of energy from renewable sources will need to create mechanisms through which electricity consumers can respond to unpredictable (and sometimes highly correlated) changes in the electricity supply. A so-called "smart grid" allows consumers to see the true price of energy and lets them adjust their consumption patterns in response. A smart grid can intelligently integrate the actions of both energy suppliers and energy consumers, generate real-time information and price signals, and thus enable a sustainable, economic, and secure electricity supply. The main challenges for a smart grid are not of a technical nature, but regulatory and behavioral. A certain exposure of consumers to price volatility is needed to make smart grids and renewable energies work.

6.4 Environmental issues

Competition with food production or biodiversity

Human activities, no matter what kind, always mean an intrusion into the natural ecosystem. For some types of energy production, as for instance solar parks or the cultivation of energy plants, great areas are needed. There can be a certain competition with areas needed for food production, areas covered by native forest (deforestation), or populated areas (resettlement of the residents).

GHG-potential of flooded areas

The same difficulties can occur by constructing dams for hydropower production and energy storage capacities: because of the minor gradient in the Amazon region, immense surfaces are flooded. This can lead to another environmental risk. Organic material in the ground can convert to methane in the shallow water and escape into the atmosphere. Methane is a GHG approximately 21 times more powerful than carbon dioxide. Areas for installing renewable energy plants should, therefore, be chosen carefully.

Negative impacts of monocultures

The prospective future energy supply is based in large part on biomass as the primary resource. Residues are considered, but Brazil has a great tradition in ethanol production from sugar cane. Energy plants are agricultural cultures and usually cultivated in monocultures, which means a reduction of biodiversity, and an increase of pesticides and irrigation water demand, in addition to the surface area required as described above.

Increase in production will compensate the land use by energy production

In this study, these environmental restrictions are considered in the potential calculations. Also, only a very small additional surface area is required. In the agricultural sector, an increase in the production processes and yields are considered more important than additional land use. Furthermore, Brazil contains vast unused or poorly used areas, which are not suitable for food production and are not vegetated by native forests.

7 Conclusions

The final energy output in 2050 of around 8,000 TWh can cover the final energy demand of Brazil up to 100%

The study shows that the modelled final energy output in 2050 of approximately 8.000 TWh can cover the modelled final energy demand of Brazil up to 100% considering the "optimistic energy consumption" scenario, and up to 90% considering the "average energy consumption" scenario. However, Brazil must invest strongly in energy source developments (solar, biomass, wind), and also in energy efficiency improvements to cover the future energy demand entirely with renewable resources.

Benefits for the Brazilian economy

Going 100% renewable can create great benefits for the Brazilian economy. The value added in the production of energy is regionalized. The country could become a technological leader in the renewable energy and energy efficiency sectors. Energy prices are less exposed to external market volatility. Moreover, Brazil can export its fossil fuel resources almost entirely. This generates high revenues, which in turn can be invested in the country's development.

The current GHG-emissions of about 400 Mio tCO_2e from fossil energy consumption would be reduced to zero (1).

The energy output in 2050 is dominated by biomass and solar power, followed by wind and hydropower.

The modelled energy output in 2050 consists entirely of renewable resources (Fig. 8): biomass is the most important resource with 39% energy output followed by solar power contributing 37%. Wind power and hydropower would represent 13% and 11%, respectively. Geothermal power only contributes 0,01% of the energy output in 2050.

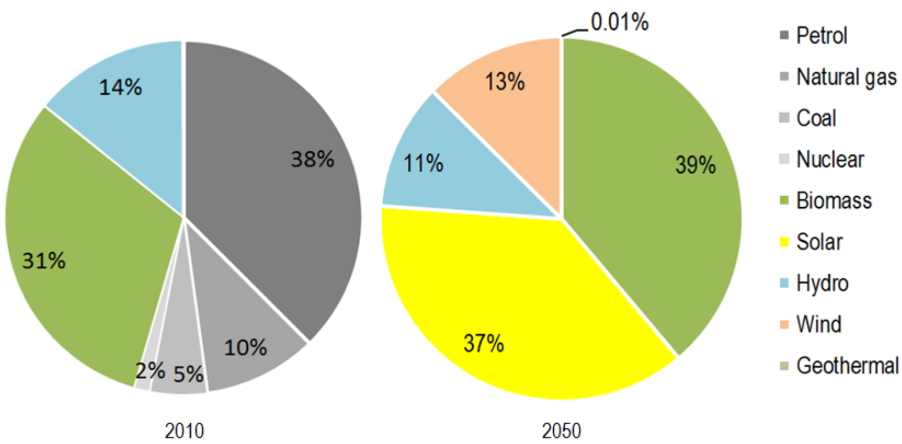
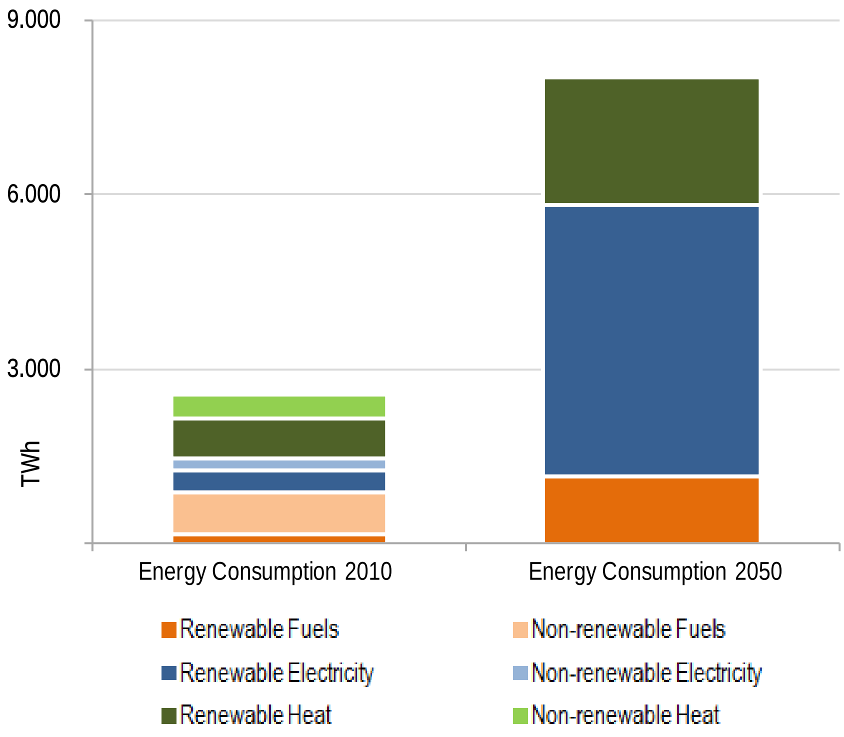


Fig. 8:
Energy output 2010 and 2050

The future final energy consumption is primarily based on electricity

While the final energy consumption for 2010 was composed of 35% liquid fuel, 20% electricity, and 45% heat, the future final energy consumption is primarily based on an electrified economy, as illustrated in Figure 9.

Fig. 9: Final energy consumption 2010 and 2050



Energy type	Energy Consumption 2010 [TWh]*		Energy Consumption 2050 [TWh]	
Renewable Fuels	152	6%	1.157	14%
Non-renewable Fuels	740	29%	-	0%
Renewable Electricity	370	14%	4.675	58%
Non-renewable Electricity	192	7%	-	0%
Renewable Heat	716	28%	2.192	27%
Non-renewable Heat	389	15%	-	0%
Transmission loss	80		246	
TOTAL	2.559	100%	8.024	100%

Storage capacities and strong transmission grids are necessary.

If the 2010 demand of transport fuel and heat stabilizes at current levels, Brazil can cover these amounts entirely in 2050. This means that the additional future energy demand from now until 2050 may be based on electricity. A large part of the new energy matrix is based on fluctuating energies. This means that storage capacities and strong transmission grids are necessary to deal with the energy production. The decentralization of energy production is advantageous as it reduces transmission losses and relieves the grids.

Mobility has to switch from fuel to electricity

Also the economic system has to be adapted to the future energy matrix. The growing mobility and transport sector have to be based on electricity. The shifting of transportation from roads to railways would be a start.

High annual investments require aligned strategies

In order to achieve the installed capacity of 2.040 GW, approximately 4.400 billion dollars should be invested by 2050. This means an annual investment of about 115 billion dollars, which represents around 5% of the current GDP and 1,5 % of the 2050 GDP. Aligned investment strategies will help to reduce the rate to 2,8 % of the 2050 GDP. A large part of the investments could be mobilized by directing fossil fuel investments, which represent approximately 70% of the current energy investments, into renewable energies. Private finance and effective public policy are needed.

Economic and long-term planning is necessary to encourage investments

It is vital to set the course as soon as possible. To encourage investments in the renovation of grids and storage capacities, it is necessary to build the decentralized power plants, work on changes in the economic system, and plan for the long-term. All renewable resources, especially solar power which is not yet given serious consideration in any governmental papers, need to be included and related programs and incentives established.

A1 Energy demand

Topdown energy demand forecast, GDP and population by 2030/2050.

Goal and method

The goal is the forecast of the total final energy demand for Brazil up to 2030/2050 based on macroeconomic indicators, such as the GDP and population. The approach is similar to BP’s energy outlook (i.e., not using a trend extrapolation from historical data, but relying on energy intensity curves). This means that energy demand trends are assessed and the national Brazilian demand is derived using assumptions on population growth, GDP growth, and changes in end-user demand. This method is justified, especially if structural changes of an economy are expected, because the often-used extrapolation (“business-as-usual”) method is unreliable.

Data

GDP per capita in the developed OECD hit 22.000 dollars per person in 2000, a 20-fold increase since the beginning of the industrial revolution (1800 AD). In the rest of the world, industrialization started later and the growth is even faster due to the catching-up phenomenon.

The 2005 GDP in PPP (purchasing-power-parity) weights from the Penn World Tables for 1970 onwards was used and linked to the Maddison (2008) series using 1990 PPP weights for earlier years, then rescaled into 2010 prices. For the period 2035 to 2050, the PwC long-term GDP PPP forecasts were used, and scaled to 2030. In the “optimistic energy consumption” scenario we reduce the GDP growth from PwC down to 85% in the period from 2030 to 2050, because we assume that the greatest growth and development will occur in the next 20 years.

The data on population by country for 1950 to 2030 are provided by the United Nations Population Division (2009). For the 2040 and 2050 figures, stabilization is assumed based on the IBGE provision.

For energy intensity, we assume that Brazil follows the world average path. The historical trend data show a massive and accelerating convergence since about 1990, toward lower levels of global energy intensity.

The differences in energy intensity across major economies are getting smaller[6].

Results

The following table shows the results of the modelling.

Brazil, optimistic scenario (relative to energy demand)	2010	2020	2030	2040	2050	
Population [Mio. CAP]	193	207	216	219	215	[1]
GDP [2010 USD, PPP]	2.190	3.202	4.424	6.120	7.668	[2]
Energy Intensity [TOE/GDP]	116	104	93	85	79	[3]
Final energy [MTOE]	254	333	407	520	606	
Final energy demand - optimistic scenario [TWh]	2.954	3.873	4.733	6.050	7.045	[4]

Development optimistic scenario	2010	2020	2030	2040	2050
Population	1,00	1,07	1,12	1,13	1,11
GDP	1,00	1,46	2,02	2,80	3,50
Energy Intensity	1,00	0,90	0,80	0,73	0,68
Final energy demand - optmistic scenario	1,00	1,31	1,60	2,05	2,38

[1] IBGE/Diretoria de Pesquisas. Coordenação de População e Indicadores Sociais. Gerência de Estudos e Análises da Dinâmica Demográfica. Projeção da População do Brasil por Sexo e Idade para o Período 1980-2050 - Revisão 2008.

[2] BP 2012 (up to 2030), PwC long-term forecast (2035-2050) with correction of PwC long-term GDP growth estimates for Brazil use 100% in 2030, 95% in 2040, 90% in 2045, 85% in 2050 of PwC 2011 forecasts:

[3] BP 2012 (up to 2030), estimate based on world trend (2035 to 2050), assuming 105 TOE/CAP for 2030, 99 fr 2035, 87 for 2040, 87 for 2045, 82 for 2050

[4] 1 MTOE = 11.63 TWh

Brazil, average scenario	2010	2020	2030	2040	2050	
Population [Mio. CAP]	193	207	216	219	215	[1]
GDP [2010 USD, PPP]	2.190	3.202	4.424	6.442	9.021	[2]
Energy Intensity [TOE/GDP]	116	104	94	88	84	[3]
Final energy [MTOE]	254	333	407	567	758	
Final energy demand - average scenario [TWh]	2.954	3.873	4.733	6.593	8.813	[4]

Development average scenario	2010	2020	2030	2040	2050
Population	1,00	1,07	1,12	1,13	1,11
GDP	1,00	1,46	2,02	2,94	4,12
Energy Intensity	1,00	0,90	0,81	0,76	0,72
Final energy demand - average scenario	1,00	1,31	1,60	2,23	2,98

[1] IBGE/Diretoria de Pesquisas. Coordenação de População e Indicadores Sociais. Gerência de Estudos e Análises da Dinâmica Demográfica. Projeção da População do Brasil por Sexo e Idade para o Período 1980-2050 - Revisão 2008.

[2] BP 2012 (up to 2030), PwC longterm forecast (2035-2050)

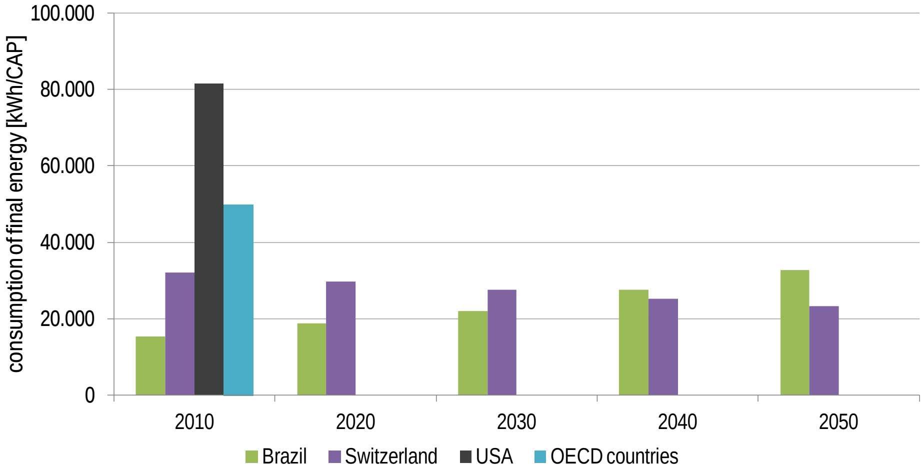
[3] BP 2012 (up to 2030), estimate based on world trend (2035 to 2050), assuming world trend TOE/CAP of 108 for 2030, 102 for 2035, 97 for 2040, 92 for 2045, 88 for 2050

[4] 1 MTOE = 11.63 TWh

6 (8) (31) (32) (2) (34) (33) (35) (36) (37) (38)

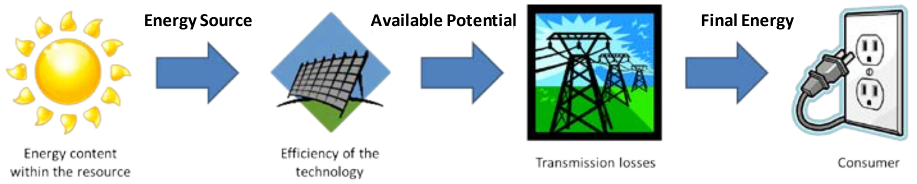
Comparison to industrial countries

In 2010, the per capita final energy consumption of Brazil was quite low, much lower than the consumption of a Swiss or US citizen, and also much lower than from citizens of the OECD. However, consumption in Brazil will increase over the next 40 years while Switzerland's will decrease, according to the "business as usual" scenario.



A2 Renewable energy potential

Definition of the different terms of energy



Energy source refers to the natural energy or heat content of the resource, (e.g., sun, wind, natural gas, or fossil oil). This primary energy can be converted by power plants and some losses occur because of the efficiency of the technology. The converted energy is an energy product such as ethanol, biogas, and electricity. After the conversion, the energy needs to be brought to the consumer, which causes transmission losses. The amount of energy reaching the consumer is called final energy.

Theoretical energy potential by source and feasible potential

Primary Energy Sources	Theoretical Potencial [GW]	Theoretical Energy [TWh]	Feasible / Theoretical %	Feasible Energy Potential 2050 [TWh]	Ref. Theoretical Potencial
Biomass		11.585		5.000	
Energetic Crops		*1.171*		*1.171*	
Sugar cane (ethanol)		485	100%	485	[1]
Oil plants*		295	100%	295	[1]
Firewood		392	100%	392	[3]
Agriculture biomass residues		*8.025*		*2.006*	
Soy residues		2.928	25%	732	[1]
Corn residues		3.576	25%	894	[1]
Sugar cane (straw)		1.065	25%	266	[1]
Rice straw		456	25%	114	[1]
Agroindustrial biomass residues		*1.710*		*1.694*	
Sugar cane (Bagasse)		1.091	100%	1.091	[1]
Black liquor		130	100%	130	[1]
Wood residues		456	100%	456	[1]
Citrus bagasse**		20	50%	10	[2]
Rusks (Coconut, Coffee, Cocoa)		13	50%	6	[2]
Urban residues		*88*	*50%*	*44*	[4]
Urban sewage		*23*	*10%*	*2,3*	[2]
Manure		*567*		*79*	
Bovine		512	*10%*	51	[5]
Pork		28	*50%*	14	[5]
Poultry		27	*50%*	14	[5]
Algae		*32*	*10%*	*3,2*	[6]
Solar	290.000	-		5.220	
Photovoltaic	*275.000*		1%	4.950	[2]
Thermal	*15.000*		1%	270	[2]
Hydro	365	-		962	
Hydropower	*251*	-		*882*	
Amazonas	106		*38%*	225	[7]
Paraná	58		*100%*	324	[7]
Tocantins / Araguaia	28		*8%*	13	[7]
São Francisco	18		*90%*	89	[7]
Atlântico Sudeste	15		*100%*	82	[7]
Uruguai	13		*100%*	72	[7]
Atlântico Sul	5		*100%*	30	[7]
Atlântico Leste	4		*100%*	23	[7]
Paraguai	3		*100%*	17	[7]
Parnaíba	1		*59%*	3	[7]
Atlântico Nordeste	1		*100%*	3	[7]
Tides and Waves	*114*		*18%*	*80*	
Wind	1.335	-		1.388	
Wind	1.335		40%	1.388	[7]
Geothermal	0,3	-		1	
Geothermal	0,3		25%	0,6	[2]
Total	291.701	11.585		12.571	

(*) - sunflower, caster, oil palm, babcu, coconut, peanut, jatropha

(**) - orange, lemon, tangerine

[1] PNE Biomassa 2030
[2] Geoklock
[3] MEN 2030
[4] PNE 2030 + Geoklock
[5] Biolatina
[6] Algae
[7] PNE Hidrelérica 2030
[8] ABEólica

A3 Biomass allocation

Resource	Ethanol 1 G	Ethanol 2 G	Small Biodiesel Plant	Large Biodiesel Plant	Micro Biogas Plant	Small Biogas Plant	Large Biogas Plant	Gasification	Solar-Powerd Gasfication	Incineration	Charcoal / Pellets	Biokerosene Plant	TOTAL
Feasible Energy Potential	480	300	50	250	47	77	484	352	152	2.275	530	3	5.000
Sugar cane (ethanol)	480												*480*
Oil plants*			50	250									*300*
Firewood										200	200		*400*
Soy residues							100	100	50	500			*750*
Corn residues							250	100	50	500			*900*
Sugar cane (straw)		100						50		100			*250*
Rice straw										100			*100*
Sugar cane (Bagasse)		200				50	100	100	50	600			*1.100*
Black liquor										130			*130*
Wood residues										120	330		*450*
Citrus bagasse**					2	2	2	2	2				*10*
Rusks (Coconut, Coffee, Cocoa)										5			*5*
Urban residues							20			20			*40*
Urban sewage							2						*2*
Bovine					25	15	10						*50*
Pork					10	5							*15*
Poultry					10	5							*15*
Algae												3	*3*

A4 Reference plants

Reference Plants	Type of energy output	Energy output	Power Output Capacity [MW]	Capacity factor [h/y]	# Plants 2050	Total Installed Capacity 2050 [MW]	Secondary Energy Production 2050 [GWh]
Biomass						536.000	3.213.234
Ethanol 1 G	Fuel	Ethanol	250	5.600	350	87.500	490.000
Ethanol 2 G	Fuel	Ethanol	100	5.600	50	5.000	42.000
Small Biodiesel Plant	Fuel	Biodiesel	5	5.600	2.000	10.000	56.000
Large Biodiesel Plant	Fuel	Biodiesel	200	5.600	200	40.000	224.000
Micro Biogas Plant	Electric	Electricity	0,5	8.000	1.500	750	6.750
Small Biogas Plant	Electric	Electricity	5	8.000	250	1.250	11.250
Large Biogas Plant	Fuel	Biomethane	100	8.000	160	16.000	128.000
Gasification	Fuel	Syngas	100	5.600	200	20.000	120.000
Solar-Powerd Gasification	Fuel	Syngas	75	5.600	200	15.000	94.500
Incineration - Electricity output	Electric	Electricity	70	5.600	1.200	84.000	506.585
Incineration - Heat output	Heat	Steam	180	5.600	1.200	216.000	1.211.350
Charcoal / Pellets	Fuel	Charcoal / Pellets	200	8.000	200	40.000	320.000
Biokerosene Plant	Fuel	Biokerosene	50	5.600	10	500	2.800
Solar						1.285.000	3.084.000
PV integrated in Buildings	Electric	Electricity	0,3	1.800	1.500.000	450.000	1.080.000
Solar Heat Plant	Heat	Hot water	0,1	1.800	2.000.000	200.000	480.000
Small PV Open-Field	Electric	Electricity	20	1.800	8.000	160.000	384.000
Large PV Open-Field	Electric	Electricity	100	1.800	4.000	400.000	960.000
Concentrated Solar Power Plant	Heat	Steam	50	1.800	1.500	75.000	180.000
Hydro						166.510	932.456
Micro Hydropower Plant	Electric	Electricity	0,5	5.600	1.000	500	2.800
Small Hydropower Plant	Electric	Electricity	20	5.600	800	16.000	89.600
Large Hydropower Plant	Electric	Electricity	1.000	5.600	150	150.000	840.000
Tidal Power Plant	Electric	Electricity	1	5.600	10	10	56
Wind						400.000	1.040.000
Small Wind Park	Electric	Electricity	50	2.600	2.000	100.000	260.000
Large Wind Park	Electric	Electricity	200	2.600	1.500	300.000	780.000
Geothermal						100	800
Deep Geothermal Heat Pump	Heat	Hot water	0,5	8.000	200	100	800
Total						2.387.610	8.270.490

* Output Energy / Reference Input Energy

Reference Plants	Primary Energy INPUT [TWh]	Primary Energy Content Reference -	Average Efficiency* 2010 [%]	Average Efficiency 2050 [%]	Max Energy Output 2050 [GWh]	Energy Output 2050 (no eff. Improv) [GWh]	Efficiency improvement [GWh]
Biomass	5.000				3.794	3.140.800	72.434
Ethanol 1 G	480	Ethanol	100%	100%	480	490.000	
Ethanol 2 G	300	Biomass	10%	20%	60	28.000	
Small Biodiesel Plant	50	Oil	100%	100%	50	56.000	
Large Biodiesel Plant	250	Oil	100%	100%	250	224.000	
Micro Biogas Plant	47	Biomass	12%	15%	7	6.000	
Small Biogas Plant	77	Biomass	12%	15%	12	10.000	
Large Biogas Plant	484	Biomass	29%	29%	138	128.000	
Gasification	352	Biomass	35%	40%	141	112.000	
Solar-Powerd Gasification	152	Biomass	40%	50%	76	84.000	
Incineration - Electricity output	2.275	Biomass	39%	45%	1.024	470.400	
Incineration - Heat output		Biomass	52%	52%	1.183	1.209.600	
Charcoal / Pellets	530	Biomass	70%	70%	371	320.000	
Biokerosene Plant	3	Oil	100%	100%	3	2.800	
Solar	5.220					2.313.000	771.000
PV integrated in Buildings	N/A	Solar irradiation	15%	25%	N/A	810.000	
Solar Heat Plant	N/A	Solar irradiation	15%	25%	N/A	360.000	
Small PV Open-Field	N/A	Solar irradiation	15%	25%	N/A	288.000	
Large PV Open-Field	N/A	Solar irradiation	15%	25%	N/A	720.000	
Concentrated Solar Power Plant	N/A	Solar irradiation	15%	25%	N/A	135.000	
Hydro	962					932.456	-
Micro Hydropower Plant	N/A	Hidropower	100%	100%	N/A	2.800	
Small Hydropower Plant	N/A	Hidropower	100%	100%	N/A	89.600	
Large Hydropower Plant	N/A	Hidropower	100%	100%	N/A	840.000	
Tidal Power Plant	N/A	Hidropower	100%	100%	N/A	56	
Wind	1.388					1.040.000	-
Small Wind Park	N/A	Windpower	100%	100%	N/A	260.000	
Large Wind Park	N/A	Windpower	100%	100%	N/A	780.000	
Geothermal	0,6					800	-
Deep Geothermal Heat Pump	N/A	Ground Heat	100%	100%	N/A	800	
Total						7.427.056	843.434

* Output Energy / Reference Input Energy

A5 Investments

The calculation of the number of plants to be built by 2050 considered the number of plants needed by 2050 deducting the number of existing plants in 2010.

Overnight capital cost will change according to the technology by 2050. In order to take this trend into consideration, a rate of adjustment was applied for some specific technologies.

Reference Plants	Type of energy output	Energy output	Power Output Capacity [MW]	# Plants 2010-2050 Total	Total Power 2050 [MW]	Overnight capital cost k USD/MW	Total investment k USD
Biomass					308.795		407.665.066
Ethanol 1 G	Fuel	Ethanol	250	200	50.000	637	31.863.995
Ethanol 2 G	Fuel	Ethanol	100	40	4.000	2.798	10.886.699
Small Biodiesel Plant	Fuel	Biodiesel	5	1.370	6.850	750	5.137.500
Large Biodiesel Plant	Fuel	Biodiesel	200	120	24.000	653	15.663.149
Micro Biogas Plant	Eletric	Electricity	0,5	1.490	745	6.977	5.197.674
Small Biogas Plant	Eletric	Electricity	5	240	1.200	5.581	6.697.674
Large Biogas Plant	Fuel	Biomethane	100	160	16.000	1.628	26.046.512
Gasification	Fuel	Syngas	100	125	12.500	1.500	18.750.000
Solar Powered Gasification	Fuel	Syngas	75	140	10.500	10.000	76.871.863
Incineration - Electricity output	Eletric	Electricity	70	730	51.100	1.500	76.650.000
Incineration- Heat output	Heat	Steam	180	730	131.400	1.000	131.400.000
Charcoal / Pellets	Fuel	Charcoal / Pellets	200	-	-	1.250	0
Biokerosene Plant	Fuel	Biokerosene	50	10	500	5.000	2.500.000
Solar					1.284.859		2.863.478.388
PV integrated in buildings	Eletric	Electricity	0,3	1.499.998	449.999	3.500	1.200.094.574
Solar Heat Plant	Heat	Hot water	0,1	1.999.000	199.900	1.000	199.900.000
Small PV Plant	Eletric	Electricity	20	7.998	159.960	3.000	368.180.438
Large PV Plant	Eletric	Electricity	100	4.000	400.000	2.500	807.826.098
Concentrated Solar Plant	Heat	Steam	50	1.500	75.000	5.000	287.477.277
Hydro					48.310		54.391.969
Micro Hydropower Plant	Eletric	Electricity	0,5	600	300	3.000	769.088
Small Hydropower Plant	Eletric	Electricity	20	400	8.000	1.800	14.400.000
Large Hydropower Plant	Eletric	Electricity	1.000	40	40.000	1.200	39.185.168
Tidal Power Plant	Eletric	Electricity	1	10	10	6.000	37.713
Wind					398.800		1.071.907.691
Small Wind Power Plant	Eletric	Electricity	50	1.980	99.000	4.500	362.288.339
Large Wind Power Plant	Eletric	Electricity	200	1.499	299.800	2.500	709.619.352
Geothermal					100		795.823
Deep Geothermal Heat Pump	Heat	Hot water	0,5	200	100	10.000	795.823
Total					2.040.864	-	4.398.238.936
						Billion USD	4.398

A6 Energy production areas

Potential area for biomass energy production

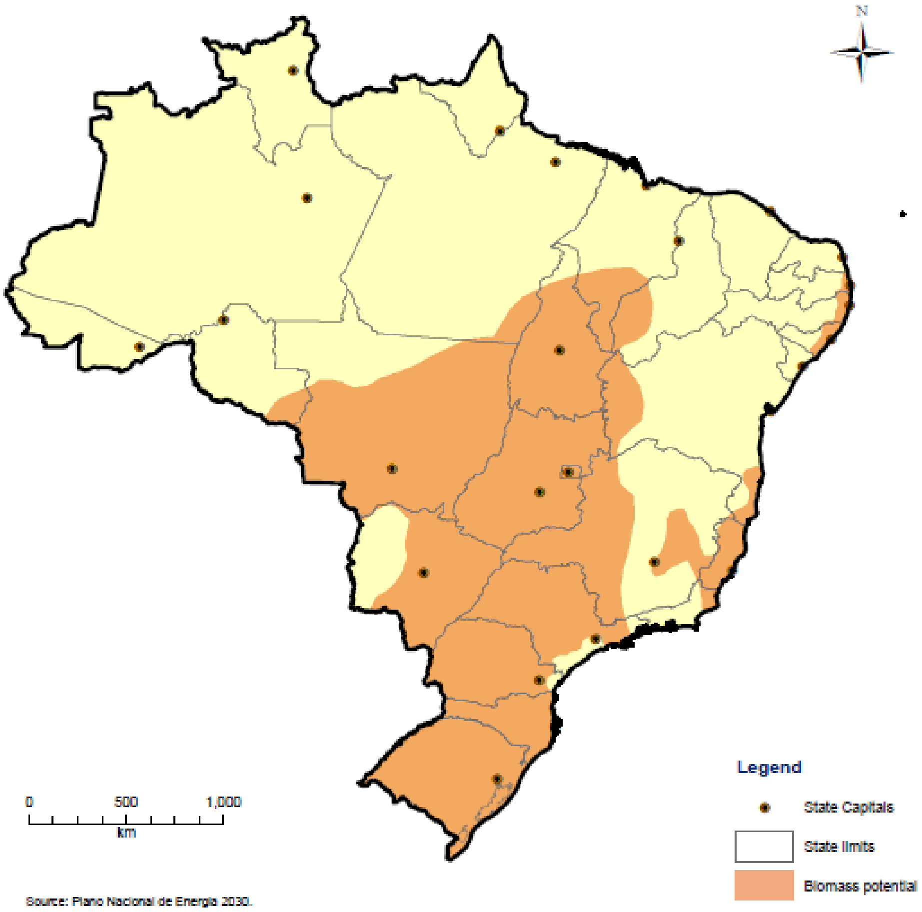


Illustration by Ekos Brasil.

Potential area for solar energy production

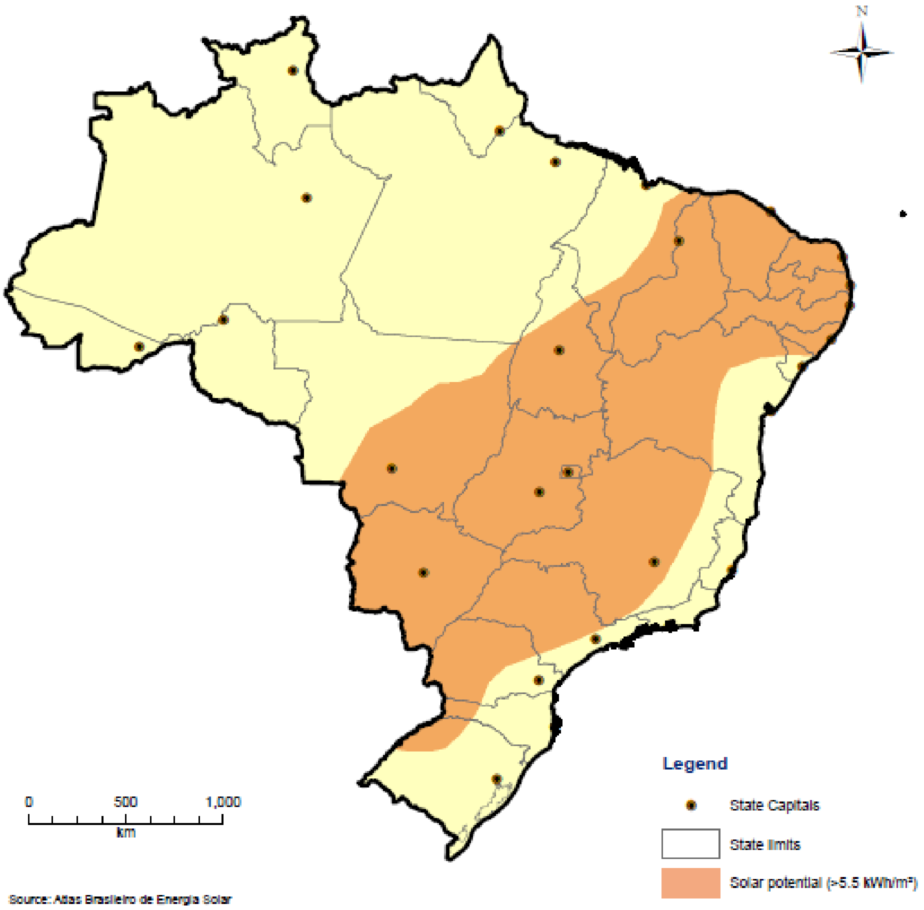


Illustration by Ekos Brasil.

Potential area for wind energy production

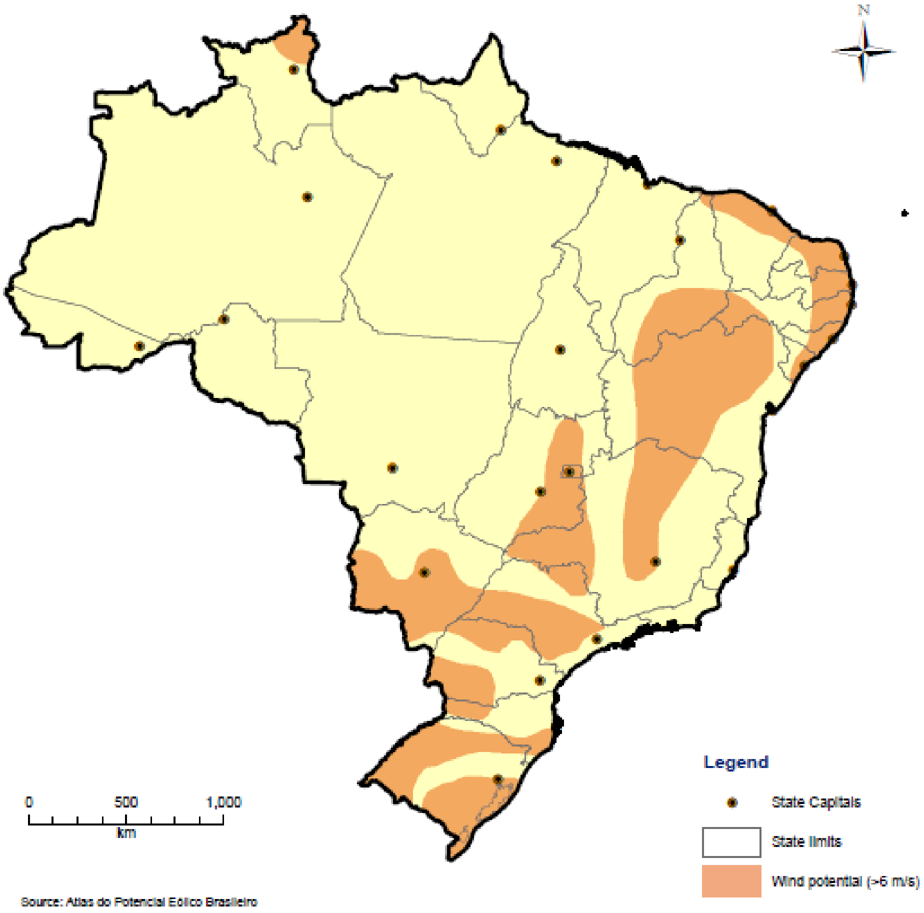


Illustration by Ekos Brasil.

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