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Spatialized potential for biomass energy production in Brazil: an overview

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Abstract

The opportunity for renewable energy production in developing countries is a theme of high relevance within the context of climate change. In this paper we explore the production of electricity in Brazil and investigate the potential for sustainable biomass energy production. This is explored in a GIS system (1) establishing the demand centers or regions (energy demand factor), (2) checking if they can be served by existing capacity and transmission (transmission lines factor), (3) deciding on new generation and whether it will an island or the main grid connection (power plants factor), (4) locating the power plant subject to the potential biomass supply accepting the environmental constraints (land use and environmental preservation factors). Results show that even though large areas have a potential for biomass energy production, the lack of investments in technological improvements and changes in the system *status quo* result in a system that does not progress towards of becoming a cleaner, safer and less dependent on climatic factors. We conclude that biomass has the potential to grow as a source of renewable and clean energy. This potential can be explored by conserving respecting the environment and encouraging the creation of decentralized systems, thereby making Brazil a key player in the climate change targets in the coming years.

Keywords: Renewable energy, Sustainable development, Biomass, New technologies, Energy matrix, Energy security

Background

Satisfying the demand for energy supply is a persistent issue in the world today. To meet the requirements of a growing population, this demand will continue to increase in the coming years (IPCC 2007). In the second half of the 20th century, a number of research has pointed to the endangerment of the life on earth due to the effects of the climate change (Socolow et al. 2004; IPCC 2007; Kates 2010; IPCC 2011; Abramovay 2014). This is a direct consequence of the higher concentration of greenhouse gases in the atmosphere, mostly CO_2 originating from fossil fuels. Non-renewable sources of energy—mostly fossil fuels—are still responsible for 85 % of the energy supply in the world (IEA 2010; IPCC 2011), an exceptionally unsustainable aspect of human society.

The first concept of Sustainable Development—"Meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations 1987)—emerges from the necessity of finding alternative forms of development. The demand for renewable energy is a direct consequence of the global movement to decrease CO_2 emissions in the atmosphere and to retard the consequences of global warming, providing greener ways of living. In 2004, 48GtCO_2-eq were emitted to the atmosphere, and approximately 26 % of this amount was released during the process of power generation and heat supply (Sims et al. 2007). Therefore, an important step to reduce the effects of greenhouse gases is to change the way in which energy is generated, focusing on a planned, intelligent, and efficient chain of power production.

The installation and use of large-scale decentralized renewable energy technologies requires significant monetary investment and relevant changes in all sectors of energy consumption, plus organizational and legislative changes, the integration of environmental considerations, and the setting of multi-criterial regional planning and public participation (von Haaren et al. 2012). According to Abramovay (2014), despite being responsible for only 3 % of the energy matrix in the world, the increasing use of *Modern Renewable Energy Sources* (solar, eolic, geotermic, and biomass) tends to exponentially lower their price and thus, make them more accessible.

Distributed energy production from renewable technologies can provide an important source of renewable environmental-friendly energy. According to Blaschke et al. (2013), around 30–45 million hectares of land would need to be converted to meet European targets for biomass supply. The same authors point out that without adequate planning competition between bioenergy, conservation, traditional agriculture, and forestry, is inevitable.

Characterized by its diverse possibilities of sources and conversion technologies for energy products, biomass has a high potential for renewable energy supply. The term biomass encompasses plant material generated through photosynthesis and all its by-products, such as forest-wood, cultivated crops, animal droppings, and organic matter (Vidal and da Hora 2011). However, of all renewable energy technologies, biomass needs the greatest area per produced unit of energy (Blaschke et al. 2013), and is associated with a high conflict potential with other spatial uses (Söderberg and Eckerberg 2013). Regarding environmental sustainability, power generation through biomass should guarantee the quality of soil, water and biodiversity cycle, lowering externalities in the long term.

Brazilian case

Brazil has a peculiar source of power generation, where hydropower is a source of almost 80 % of the total energy supply in an extremely centralized system (EPE 2014). When a risk of blackouts is eminent, thermoelectric plants become the government guarantee that the energy system is safe. In 2014, they were responsible for 27 % of Brazil's energy (EPE 2014). About 70 % of the country's hydropower potential is located in the Amazon and Cerrado (Ferreira et al. 2014) (Fig. 1), the two biggest Brazilian biomes, both with high levels of species endangerment. The impact of those projects, both on nature and on the way of life of the local communities around the rivers, is impossible to avoid. Even with the Brazilian Environment Ministry imposing a series of conditions for the licensing of the projects, it is not uncommon to see the continued construction of dams, which defy these constraints and consequently create irreversible social and environmental impact (Fearnside 2009; Abramovay 2014).

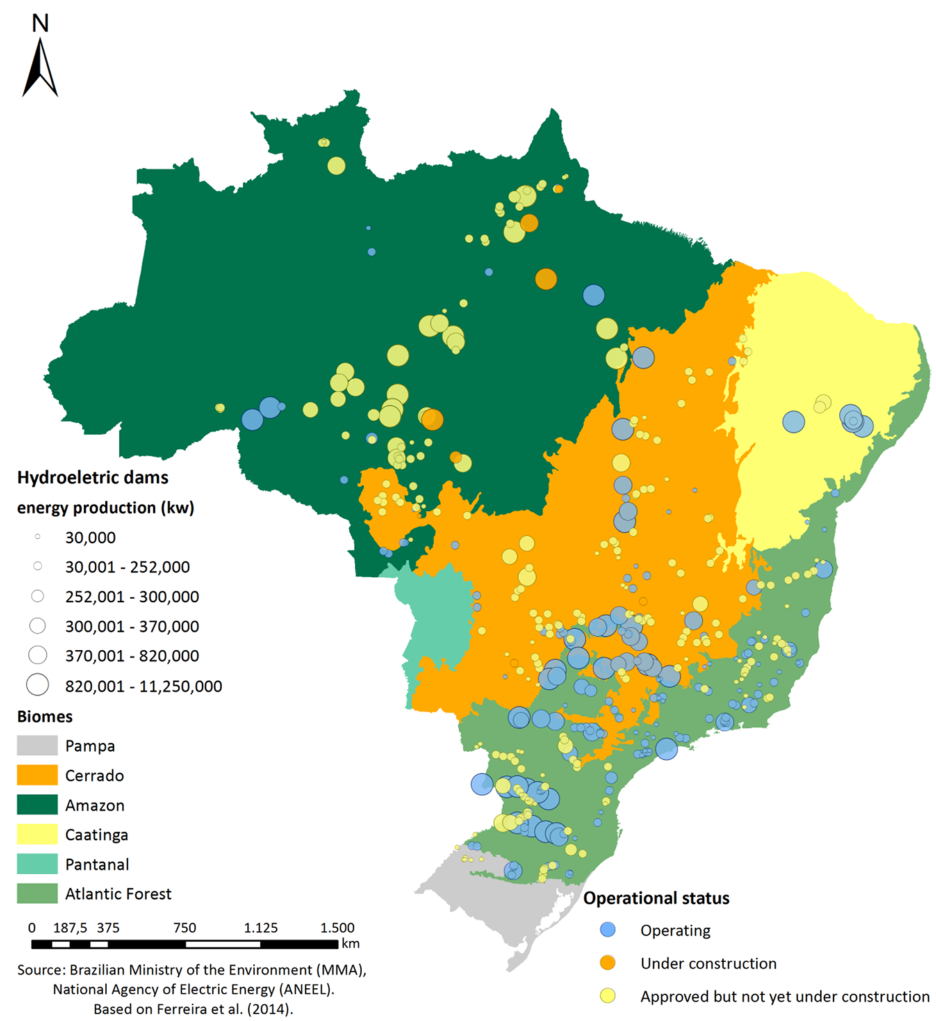

Fig. 1 Panorama of hydroelectric dams in Brazil

Having experienced an unexpectedly weak rainy season in 2013–2015, with a low amount of rainfall, the Brazilian population has had to deal with the consequences of an electrical system that is highly dependent on only one technology and the associated effects of water and energy rationing in the country's largest cities and its regions (Escobar 2015; Brasileiro 2014; Corrêa 2014). Without proper investment in the sector, which currently focuses on a few *capacity* increases and not *efficiency* increases, without the necessary water quantity, and without an alternative source of clean energy, the country is appealing as never before to thermoelectric energy to meet its demand, making the system more expensive and environmentally dirty (Gomes 2014).

Being a pioneer in the use of biofuels (Goldemberg 2008), biomass currently contributes to only 7 % of the total share of electricity in Brazil. According to the trend of decarbonizing energy production, based on the 2050 reduction targets of CO_2 emissions and the recent target of a 20 % increase in the share of renewable energy (other than hydropower) in electricity generation in the country by 2030 (Mason and Volcovici 2015; Plaisant 2015), the prospect of potential energy production through biomass in Brazil has become an important factor for the country's decision-makers. Even though it is currently an expensive source of energy, the increased use of biomass tends to lower the production costs.

In Brazil, the generation of energy from biomass is chiefly sourced from sugarcane bagasse, eucalyptus, and wood byproducts (Tolmasquim et al. 2007). The sugarcane production is a traditional activity in the country since the colonial period (Santos et al. 2015) and is the main responsible for the biomass energy production. The bagasse, a byproduct of sugarcane beneficiation, is commonly used to generate energy for self-supply in sugar-ethanol companies (Dantas et al. 2013). In addition, eucalyptus, planted on a large scale throughout the country for cellulose, paper and wood production, has recently begun to be used also for energy production. For this purpose, fast cycle plantations of eucalyptus have been established and are achieving good results (Cortez et al. 2009).

A commonality between the two main crops used for energy production in the country, are the major environmental impacts caused by their monocultures. Both eucalyptus and sugarcane tend to be cultivated in large-scales by large-scale companies. This results in a loss of biodiversity and impacts on the communities in the region and their way of life (Muñoz 2007).

Some cases of biomass energy production are also carried out on smaller scales (Agostinho and Ortega 2012). One example of such a project is implemented in the Brazilian Amazon by a small community. Using byproducts from the timber industry and other local crops, they generated electricity for approximately 400 people who previously had no access to it (Velázquez et al. 2010). Despite the existence of legislative programs, the high short term cost always appears to be the main issue limiting the application of new technologies in the country (Lampreia et al. 2011).

In this context, this study aims to explore Brazilian electricity production and investigate the spatial potential of biomass energy production in the country. To address this target, we answered the following questions: What are the struggles and the potentials of the energy sector in Brazil? Which are the spatial possibilities for biomass energy production? Considering the existing resources of each region, where the production of biomass for power generation in Brazil could be viable?

Methods

With the aim of achieving sustainability in electricity generation, five factors were determined for analysis: energy demand factor, transmission lines factor, power plants factor, land use factor, and preservation factor (Table 1). The database used in the research was selected in regard to the relevant aspects important for investigation of locations with high potential for power production.

The energy factor focuses on the energy demand in the country per state. This factor was chosen in order to highlight the spatial potential in areas where the energy is most needed. The energy demand from 2013, in each state, was divided by its population to be able to show the demand *per capita*. This factor was generated adding the data from the Brazilian Energetic Agency with the country vector. The state scale was chosen considering that this data is not available for all the 5.570 municipalities in the country.

Table 1 Criterias adopted for the area selection

	Factors	Criteria	Goal
1	Energy demand factor (Download in March of 2015 from http://goo.gl/iMiMzO)	Areas with greater demand for energy/inhabitant will have a greater need energy production	Locate places with higher demand
2	Transmission lines factor (Download in March of 2015 from http://goo.gl/6vBU0n)	More remote area is of a installed transmission line, greater is the need	Encourage a decentralized system
3	Power plants factor (Download in March of 2015 from http://goo.gl/iMiMzO)	The lower energy production density in the region, the greater is its need	Generate new production areas
4	Land use factor (Download in March of 2015 from http://goo.gl/xcscy)	Areas with an anthropic land use will have a greater need	Conservation of native vegetation
5	Preservation factor (Download in March of 2015 from http://goo.gl/4khjso)	Areas of relevance for environment preservation present less need for energy production	Preservation of key areas for environmental conservation

The transmission lines and the power plants factors are connected by the issue of supply availability. These factors should comprise of areas that are not well connected with existing lines in the country, encouraging a new connection or importantly, indicating a potential area for a decentralized system. The transmission lines factor was included in the analysis with five different buffers: 5, 10, 20, 50, and more than 51 km. With this, we planned to scale the effort of new connections, as the area extends far from existing transmission lines. For the power plants factor, a simple point was given for areas with hydroelectric or thermoelectric power source, locating areas without any power source.

Finally, the two last factors, land use and preservation, aim to avoid the use of native vegetation for energy production and locate areas with the most suitable potential sources. Both were chosen considering that to base a study only in the land use or the priority areas for conservation would let a gap between places with remains of native vegetation and places with a great relevance for the biodiversity in the country. The classification of the land use areas assigned a greater potential to disturbed areas, to save the native vegetation. The energy should be generated through the capacity already installed in the area, not being necessary to open new areas or change the local main activity. The preservation factor is based on a detailed study conducted by the Brazilian Environment Ministry, involving scientists from universities, the government, and NGO's. This study collected data about biodiversity, resulting in a map of areas showing where usage would endanger the ecosystem in the given region.

Database

The database was used in vector format and was acquired from official Brazilian government websites. The scale of the data is 1:5.000.000, the default scale from the official website database for the entire country.

The organization of the database was based on the criteria adopted for the selection of the ideal areas. For every factor, values were assigned on a scale of 1–5, with the lowest value (1) for the ideal feature for selection and the highest value, 5, to the less suitable areas. To calculate the demand for energy, for example, the value 1 was allocated to the states with the highest demand for electricity. This value increased gradually until the states with the lowest demand for energy were reached, which had the designated value 5. This logic was applied for the five vectors used in the analysis.

The analyzed layers were combined through a simple layer math in the software ArcGis 10.3, generating a file with values ranging from 5 to 25 (Fig. 2). In the resulting map, areas with the value 5 were considered extremely suitable, according to the chosen criteria. Areas with the value 25 were considered extremely unsuitable (Fig. 2).

Results

The description focuses on the areas that have a final score between 5 and 7. We considered that the areas with results above 7 would bring too many adverse characteristics to the final investigation. The grouping system sought to separate the results into relevant classes. The first group (5–7) indicates the most significant areas for the study, where the characteristics fit with the desired goals. The second and the third group (8–14 and 15–21) contain intermediate areas of equal intervals. While the second group is positioned more closely to the suitable areas, the other is more associated with the less suitable. Finally, the last group (22–25) comprises of the worst areas, where the features were less favorable for power generation through biomass.

Figure 3 shows that this demand is concentrated in the Southeast region, an area with 42 % of the country's population (85.115.623 people) (IBGE 2014).

The supply availability is represented in Fig. 4. The centralized system is evident in both the transmissions lines (Fig. 4a) and in the energy sources (Fig. 4b). By overlaying both images from Fig. 4, it is possible to notice that the incidence of the transmission lines is concentrated in the locations with power sources. Another possible association is the connection between the distribution of power plants (Fig. 4b) and the agriculture areas, illustrated in the land use figure (Fig. 5a).

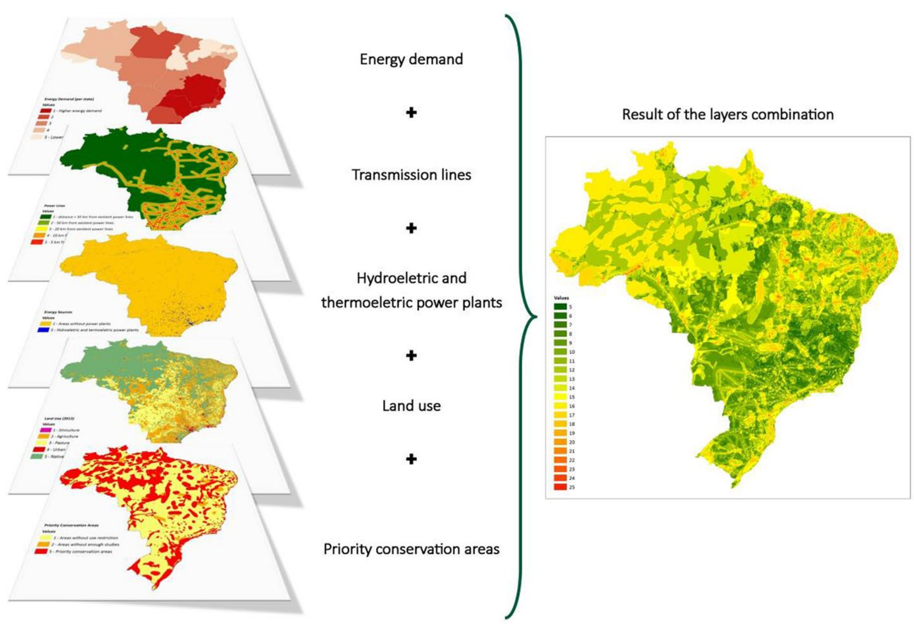

Fig. 2 Layers math scheme

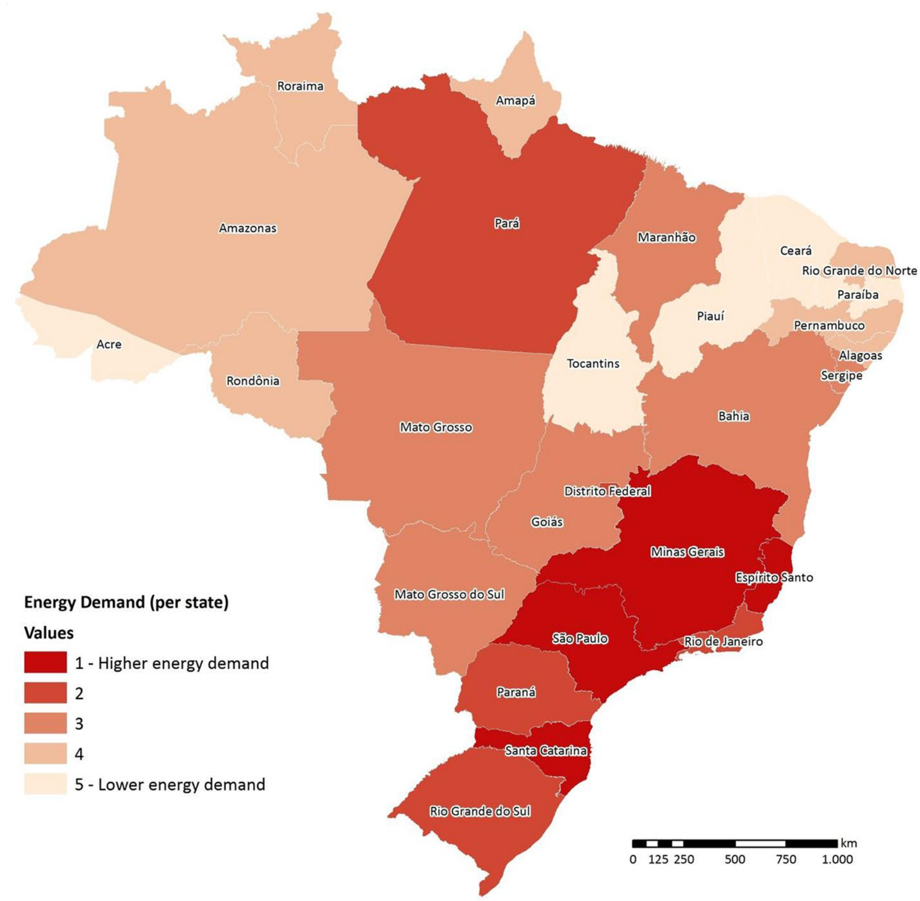

Fig. 3 Energy demand in Brazil (*Source* National Agency of Electric Energy—ANEEL)

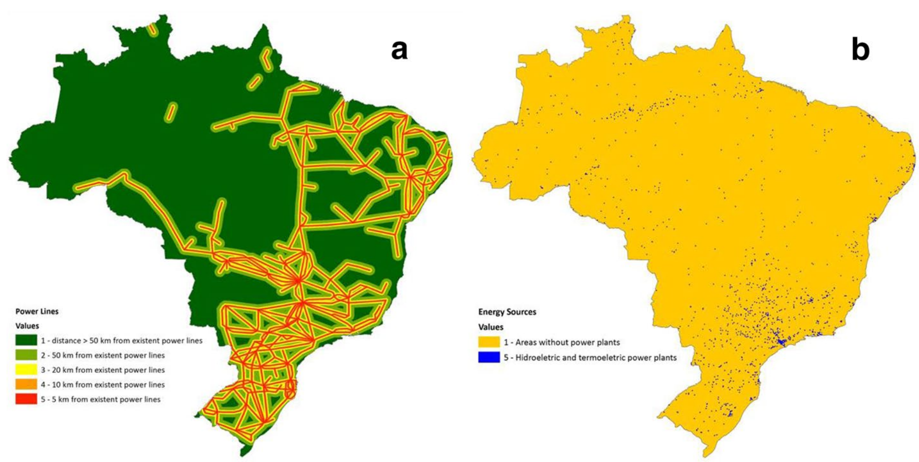

Fig. 4 **a** Transmission lines; **b** hydroelectric and thermoelectric power plants (*Source* National Agency of Electric Energy—ANEEL)

In Fig. 5, the potential availability of biomass is shown. The land use (Fig. 5a) shows that the remnant native vegetation is highly concentrated in the Northern region, where the Amazon Forest is located. The figure illustrating the priority conservation areas

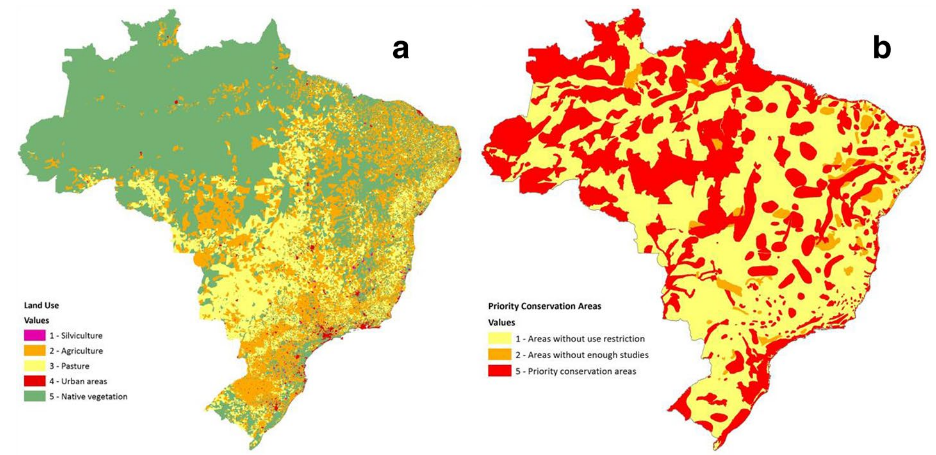

Fig. 5 **a** Land use; **b** priority conservation areas (*Source* Environment Ministry—MMA)

(Fig. 5b), similarly shows that there are a greater quantity of priority areas in the northern region, demonstrating the large relevance of these natural areas. On the other hand, conservation areas in places with high human disturbance can be extremely vulnerable, reinforcing the significance of this factor.

The results are presented in Fig. 6 and were analyzed per state, with the computed areas showing the greatest potential for energy production through biomass. The Southeast, Midwest, and Southern regions had the greatest number of areas with a potential for energy production.

Summarizing the results by state, only two states, when combined, held about 52 % of the best areas for energy production (Table 2).

Discussion

In other country-scale research, conducted for instance in Uganda and Thailand (Okello et al. 2013; Jenjariyakosoln et al. 2014), unexplored potential for biomass energy production is presented. Brazil does not show any contrary results when compared to such studies, even when examining large areas with potentials for production. One of the main reasons is that the lack of investments in technological improvements and changes in the system *status quo* result in a stationary system, which does not advance in the direction of becoming a cleaner, safer and less dependent on climatic factors. For the Brazilian case, Abramovay (2014) highlights that the country is following the path of the developed countries, investing first in polluting technologies (thermoelectric) and to only later make the shift to renewable energy. Over the past decades, Germany has been directing its efforts to change the way energy is produced in the country: primarily due to increased concerns about the environment, followed by environmental conventions and treaties on global scale (i.e. ECO 92 and Kyoto Protocol). Fighting climate change, reducing energy imports, stimulating technology innovation and a green economy, reducing or eliminating the risks of nuclear power, energy security, strengthening local economies, and providing social justice are some of the reasons why the country

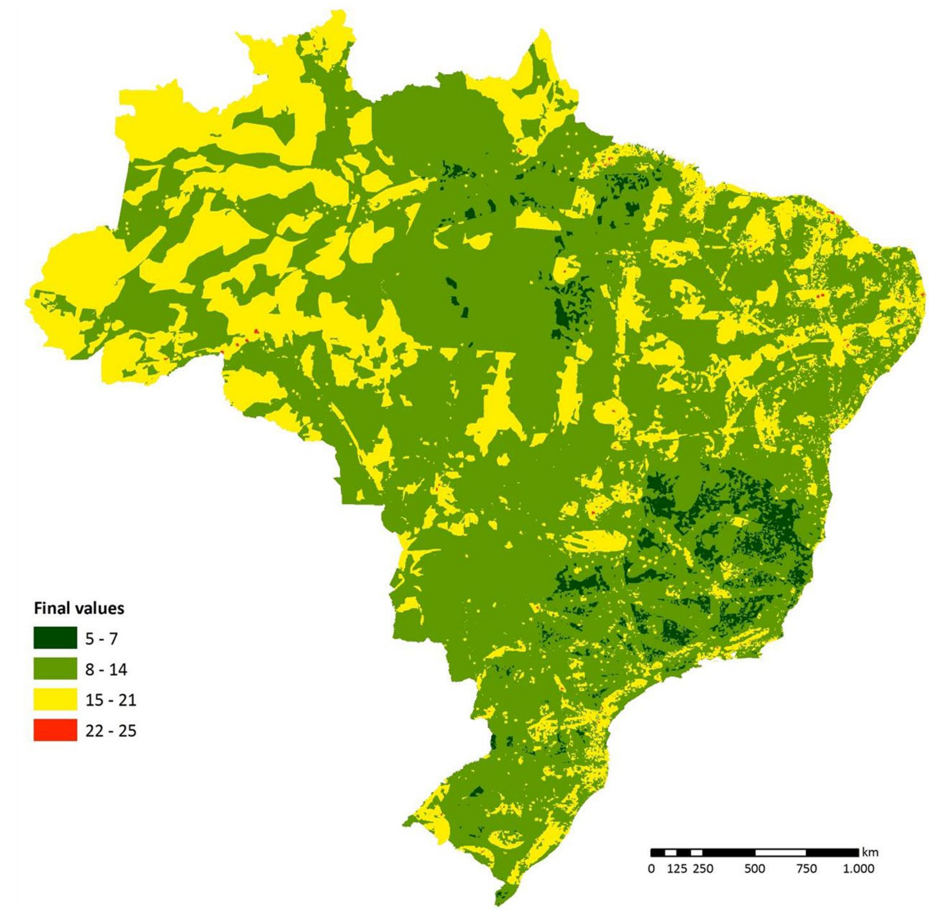

Fig. 6 Grouped results of the analyzed layers combination

Table 2 States with the best results

	State	Value	Frequency	Hectares	Sum hectares	HA total/state	% state area
1	Minas Gerais	5	8	86.709,72	18.249.606,78	65.231.313,67	27.98
		6	243	6.294.118,88			
		7	457	11.868.778,18			
2	Espírito Santo	5	3	46.471,54	1.288.300,00	5.187.497,70	24.83
		6	19	376.927,24			
		7	49	864.901,22			
3	São Paulo	5	1	2.418,17	2.329.327,23	28.926.735,36	8.05
		6	23	131.138,88			
		7	155	2.195.770,18			
4	Santa Catarina	6	4	6.620,87	615.695,36	11.996.020,69	5.13
		7	32	609.074,49			
5	Pará	7	128	5.724.936,48	5.724.936,48	125.727.312,64	4.55
6	Rio Grande do Sul	7	22	373.113,90	373.113,90	37.374.972,22	1.00

is investing in clean energy (Runci 2005; Morris and Pehnt 2012). For developing countries, the adoption of cleaner technologies at an early stage has the potential to save a lot of effort, money, and natural resources.

Even not being well connected to the national power grid, according to our results, most of Brazil's Northern region did not have favorable grades for energy production through biomass power plants. This region encompasses most of the Brazilian Amazon Forest, a factor that adds a high relevance concerning land use change and environmental preservation. Nevertheless, according to Fuso Nerini et al. (2014), the region has a potential for energy production from the residues of local agricultural production activities. This is a topic not yet well included in the country's energy agenda, one that could create a good scenario for decentralized renewable energy production.

Since 2003, the Brazilian government has been investing in multiplying the population's access to energy through the large scale program *Luz para Todos* (Light for all). In the last 10 years, the program has suceeded in supplying electricity to over 15 million people in the country (MDA 2013). Even with these advances, most of the new connections were based on a grid extension approach (Gómez and Silveira 2012), which still excludes around 200 thousand households in isolated communities. In some of these communities, an off grid solution would be the only way for people to have energy. These offgrid systems exist in some places but are mostly based on diesel generator technology, which is a very unsustainable power source that has an enormous dependency on informal sellers. Decentralized biomass energy may be a viable sustainable alternative.

The three states with the best scores—Minas Gerais, Espírito Santo, and São Paulo—are part of the Southeast region. This region is responsible for 55 % of the total Brazilian GDP (IBGE 2012), a consequence of the large amount of industries, commerce, the larger share of the country's population and energy connections. Even though the region contains many deforested areas, the higher demand for energy and its history of intensive agricultural use has contributed to the regions good grade. The Atlantic Forest biome that used to cover most of São Paulo state, for example, today occupies only 15 % of its original area (Fundação SOS Mata Atlântica et al. 2015). This region is the most vulnerable to blackouts, due to its higher energy demand as from its empty water reservoirs during the 2013–2015 water crisis. In this context, biomass energy could act as a complementary source of energy, bringing together source opportunities with the energy demand. This would make the region system safer as it would help to reduce the water usage for power production, thereby enhancing the sustainability of the system.

Considering the environmental impact caused by large scale biomass production, a mixed system between biomass and other renewables would contribute to attend the region's demand in a sustainable way. Also, the country has a large amount of degraded and unused areas, lacking of aptitude to produce food, but with no obstacles to produce biomass. So, with the proper investments, planning and an adequate range of sources, mixed systems of energy could be a reliable solution (Ambec and Crampes 2012), making possible relevant economies of scale for energy generation and storage (Elliott 2016). The modernization of the transmission system, not based in large connections but more focused on the local production-consume, could also help the country to meet the demand in a secure and reliable way. According to Armstrong et al. (2016), the future of the energy networks relies in a distributed, multi-source and multidirectional system. The biomass energy can fit those conditions, becoming a promising clean source.

The state of Minas Gerais, which had the best score, was where the first hydropower plant was located in the country. Even though it is a state with a high level of biodiversity, mostly caused by the different biomes found in its area (Klink and Machado 2005)—Savanna, Atlantic forest and Dry forest—the areas historic land use of agriculture and mining has removed a big portion of native vegetation. The state has the third highest GDP in the country, mainly due to the mining industry and activities related to it (FJP 2012). The development of a robust and sustainable system of renewable energy would lower the pressure and dependency on the hydropower system, allowing the region to develop socially and economically in an environmentally friendly way.

Conclusions

The domination of hydropower as an energy source in the country acts as an inhibiting factor for the emergence of newer technologies. The water crisis in 2013–2015 exposed the fragility of a system that relies only on one source. This article shows that, even with an energy source with a low rate of use in the country, biomass has a potential to grow as a renewable and cleaner supplier of energy in the coming years. This potential can be explored with respect to the environment and can encourage the creation of mixed and decentralized systems, placing Brazil as a key player in the climate change targets in the coming years.

The scale of the data used in the analysis may incorporate a factor uncertainty in the study due to the scale 1:5.000.000 being used, which is not ideal for exact accuracy. However, considering the country's size, this is the finest scale with available homogeny data that can be used. Further studies with a more accurate scale should be conducted in the areas with the higher potential, creating the possibility to develop a regional plan for biomass use. An assessment on the potential of using marginal, unused and contaminated areas to cultivate biomass plants should also be led, as a possible alternative that aims to save the native vegetation and not threat the country's food security.

Authors' contributions

The research was conceived by APR and MR, conducted and written by APR under supervision of MR. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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