Bringing to light a new energy path: the case of Minas Gerais State, Brazil

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Research

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Abstract

Background

In Brazil, more than 60% of the energy comes from hydroelectricity, making the system highly vulnerable in the context of global climate change, with precipitation and temperature shifts over the years. Characterized by its multiple opportunities of sources and conversion technologies for energy, biomass has a high potential to become responsible for a relevant share on the renewable energy supply. Previous studies on biomass energy production in Brazil confirm promising results. This paper highlights possibilities for biomass power generation in Minas Gerais State. To estimate the energy productivity, a Sustainable Technical Coefficient was adopted: a conservative index that considerers the portion of residues that could be used maintaining the integrity of the soil.

Results

This index was applied, together with the data on the silviculture and selected crops yield. The local energy demand was also calculated and compared to the potential energy production. Results show that 78% of the municipalities could have their basic energy needs and 18% of the demand for productive uses met by residues of crops and silviculture production.

Conclusion

For the state Minas Gerais, with its tradition of agriculture, the biomass residual energy is viable and should be considered by policymakers.

1. Introduction

Brazil presents a unique model for the structural development of an energy sector: having made advances in technology for hydropower since the 19th century, which have dominated the country's energy matrix since the 1970s. During this period, several supply crises were faced. The most severe occurred in 2001, where general blackouts began to take place. This marked a turning point in the country, with the resumption of energy projects to guarantee the supply of energy to the population. Interestingly, the source of most of this energy remained the same: hydroelectricity (Gomes et al. 2002). The two biomes with the highest levels of species endangerment and fragmentation, the Cerrado and Amazon (Vedovato et al. 2016; de Oliveira et al. 2017), contain about 70% of the potentials for hydropower production (Ferreira et al. 2014). The negative impacts of the projects on the way of life of local communities on the river's surroundings and nature are hard to avoid. Regardless of the Brazilian Environment Agency requiring specific conditions and limitations for the execution of such projects, the dam's construction continued to defy these restrictions and create irreparable impacts on the environment and social areas (Fearnside 2009; Fearnside and Pueyo 2012; Abramovay 2014; Fuchs 2016; Winemiller

et al. 2016). Moran et al. (2018) point that without considering the real social, environmental and cultural costs involved in the water dams construction, it cannot be considered a sustainable source of energy.

In the context of global climate change, Brazil has experienced precipitation and temperature shifts over recent years. Considering the lack of seasonality in Brazil, the impact of these shifts on electricity generation has been massive and has negatively impacted the population's quality of life. More than 60% of the energy for the whole country comes from hydroelectricity, obtained from a mix of energy sources that makes the system highly vulnerable (chart 1) (EPE 2018). Without investment in the sector, the necessary amount of water, and without alternative sources of clean energy, the country is dependent more than ever on natural gas thermoelectric energy generation as an alternative to meet its demand (Welfle 2017). This makes the system expensive and harmful to the environment (Gomes 2014).

A relevant change in the energy sector requires investment, legislative and organizational changes, combining environmental considerations and a set of multi-criteria local planning and public participation (Haaren et al. 2012). According to Abramovay (2014), despite being responsible for a small share of the world's energy matrix (3%), the increasing use of modern renewable energy sources (solar, wind, geothermal and modern biomass) lean towards to exponentially lower their costs and thus, make them more generally accessible. A distributed energy production system from renewable technologies would be able to provide a central source of renewable environmental-friendly energy.

Biomass energy is characterized by its diverse sorts of sources and conversion technologies for energy, presenting a relevant potential for supply through renewable energy. The term biomass includes plant material produced through photosynthesis and all its by-products, as cultivated crops, forest-wood, animal manures and organic matter (Vidal and da Hora 2011). A considerable amount of research has already been developed on the topic of cleaner, cheaper and accessible energy sources in a diverse sort of regions such as Peru (Lillo et al. 2015), Spain (Díaz-Cuevas et al. 2019), Italy (Palmas et al. 2012), Greece (Skoulou et al. 2011), Germany (Palmas et al. 2015), South Africa (Batidzirai et al. 2016) and Southern Asia (Bhattacharyya 2014), as some examples of the many researches present different methods to explore the best opportunities for renewable energy generation. Responsible for 8,2% of the energy supply in Brazil (EPE 2018), previous studies on biomass energy production conclude that it is an option that should be considered on the development of the country's energy sector. In the Brazilian Atlas of Bioenergy (Coelho et al. 2012), a national-wide methodology was presented. There, it was considered residual energy production from agriculture and silviculture activities, liquid swine sewage and solid urban waste in sanitary landfills. Maps were used to present the results to each region of the country, considering different conversion efficiency scenarios.

The Rural Residues Energetic Inventory (EPE 2014) was produced by the Brazilian Energy Research Company in order to explore the potential as energy source from agriculture, agroindustry and livestock residues. A summary of different sources was presented, detailing the agriculture production and the estimation of its residues. A potential of 48 million toe for the agriculture and livestock waste was

estimated, considering different conversion technologies, presented regarding the technical potential for biomethane and energy production.

Another example of biomass energy potential assessment in Brazil is the Biomass Residues as Energy Source to Improve Energy Access and Local Economic Activity in low HDI regions of Brazil and Colombia (BREA Project) (GBIO et al. 2015). In a cooperative effort between Brazilian and Colombian scientists, a complete data set on energy generation from residues was presented. The target of the study was to “develop a better knowledge of energy requirements for productive purposes among poor households in urban and rural areas of Brazil and Colombia (many of them in isolated regions), which could allow inputs for targeted policy interventions” (GBIO et al. 2015, p. 23). The methodology encompassed an assessment of different conversion technologies, potentials, policies, scenarios, and barriers to the development of bioenergy for 32 municipalities in the Brazilian Amazonian region.

Regarding other renewable energy sources, biomass energy requires needs the major area per produced energy unit (Blaschke et al. 2013a), and it could be related to a potential conflict with other land uses (Söderberg and Eckerberg 2013). Without considering careful planning, the competition between biomass energy, conservation, agriculture, and forestry is inevitable (Blaschke et al. 2013b). Concerning sustainability, any enterprise that seeks biomass as a source of power must guarantee the soil health, the biodiversity and water cycle, lowering the negative impacts in the long term.

One alternative for minimizing negative environmental impacts of biomass use and ensuring sustainability is to produce energy from cultivation residues, thereby bringing more opportunities to the local population. Several agricultural systems base their natural cycle on nutrient recycling, where part or certain residue of the main crop is left on the soil, to protect it physically from rain, sun, and wind and to nurture soil biota. The crop residue retention is, in fact, one of the three pillars of Conservation Agriculture (Hobbs et al. 2008; Sommer et al. 2018). This measure can avoid the necessity of the input of fertilizers and protect against soil degradation, as well as increase the carbon sequestration in the soil. However, some studies point out that there is no need to place all the residues on the soil. In some cases, a proportion can be removed without causing harm to the integrity of the soil (Dias et al. 2012; EPE 2014; Foelkel 2016).

In a country such as Brazil, where hydro energy represents not only the highest share in the energy matrix but also a fragile energy source in a climate change context, the assessment of alternatives that minimize environmental impacts, promote the sustainable development of the population, and guarantee the energy security should be seriously considered. In this paper, an estimation of the regional potential of energy production from biomass residues is assessed; recommendations from literature for how much residue could be removed without damaging the soil is also considered. This potential energy production is compared to the local energy demand. We aimed to answer the following questions:

- How much energy from residues can be produced sustainably without compromising the soil?
- Can sustainable potential meet the local demand for energy?

According to Ribeiro and Rode (2016), the state of Minas Gerais in Brazil presents favorable characteristics for the development of biomass energy initiatives. The authors conducted an analysis with the objective of finding ideal regions to develop new biomass energy initiatives, considering the local demand, transmission lines, existing energy sources and environmental constraints (land use and environmental preservation factors). The state of Minas Gerais presented the higher potential for proving the sources to the development of a biomass energy initiative, respecting the environment fragilities and its regulations.

Minas Gerais gained importance during colonial times mainly from the wealth coming from its abundance of gold. With the exhaustion of these sources and the decline of the mining industry in the early nineteenth century, agriculture emerged as an important economic activity of the region. Considered by some authors as a period of stagnation and decay, the exhaustion of the gold mining activity left society more diverse, and one which demanded different agricultural products. This led to the structuring of a productive and commercial sector that aimed to meet these internal demands.

The industrial sector is the second largest in the Minas Gerais economy, accounting for about 29.5% of the state's GDP (IBGE 2017a), with the iron mining industry leading this economic sector. The state also stands out in the production of automobiles, steel products, cement, chemicals, and food. Minas Gerais also presents the third largest economy in Brazil, participating with approximately 8.7% of the Brazilian GDP, behind only the states of São Paulo and Rio de Janeiro (IBGE 2017a). The main agricultural goods produced are coffee, sugar, milk, various types of meats, soy, corn, and beans. In 2008, the exportation from the agribusiness reached US$ 5.9 billion, corresponding to 8.2% of Brazilian agribusiness exports that year (Bastos and Gomes 2011). The rural universe dominates the cultural identity of the population that, despite being known as *miners* (mineiros), has a historical and affective cultural relationship with the countryside culture (Souza 2013).

The Brazilian electrical distribution sector is mainly divided by state. Until the early 1990s, most of the states governments were the owners of the companies that provide the local operations on the energy distribution system (Tovar et al. 2010). This condition changed with the privatizations that came along to reduce the debt of a system that experienced rapid growth during the 1960s and 1970s and culminated in a profound crisis on the 1980s (Fagundes de Almeida and Queiroz Pinto Junior 2000; Lorenzo 2002; Tovar et al. 2010). The privatization wave did not reach the state of Minas Gerais, where the same company, CEMIG (Minas Gerais Energy Company), is responsible for the concessions of 96% of the state. CEMIG also figures as one of the few companies in the country that join the tasks of generation, distribution, transmission, and commercialization of energy (CEMIG 2012).

Considering the necessity of choosing a study area, the state unit appears as the most appropriate option, since besides having uniformity in the electric system, it also presents a political management unit, a factor that facilitates the creation and application of policies. The state of Minas Gerais has positive environmental and economic characteristics for the development of this study. Therefore, has been elected as the focus area of this paper

To analyze the self-sufficiency in sustainable bioenergy of a federative unit with the fourth largest territorial area, the second largest number of inhabitants and the largest number of municipalities in the country (IBGE 2017a) aims to bring light to the possible new paths that can guide the decision making on the direction of sustainable energy diversification in Brazilian energy matrix.

2. Material And Methods

2.1. Productivity data Analysis

In order to assess the distribution of biomass residues in the state of Minas Gerais from annual crops, permanent crops, and silviculture production was downloaded from the governmental SIDRA (SIDRA - IBGE 2015a) platform. For annual and permanent crops, data was collected considering the crops that are produced in the entire state area, some predominantly in a large-scale agricultural model (corn, sugarcane, and coffee), and another more commonly in a family production model (manioc). Municipalities that had a production rate of higher than 1,000 tonnes per year in the last agriculture census were selected to be analyzed. The intention of this was to calculate the potential for municipalities where the yield would make the installation of an energy production unit worthwhile. The chosen crops were coffee, corn, beans, manioc, and sugarcane. The assessment of production data is important for the estimation of the amount of residues generated during the production process. For all the crops, the literature indicates a percentage of rests remaining from harvesting or primary processing.

For the silviculture, we selected data pertaining to the production of eucalyptus charcoal, firewood and wood in 2016. To ensure the sustainability of the process, data regarding wood products from native vegetation was not considered in this study. From the total of 853 municipalities in the state of Minas Gerais, 804 met the conditions and were analyzed.

For all the energy sources the maintenance of current land use was presupposed. Considering that the state of Minas Gerais has around 30% of its original vegetation cover (Carvalho et al. 2008), this research estimates an energy production that excludes the conversion of preserved areas into agriculture or silviculture areas. Another principle followed was to guarantee that the competition of uses between energy and food would not occur, ensuring not only productivity but also sustainability (Ribeiro and Rode 2016).

Considering soil integrity as a main necessity for the continuation of production activities, for crops and silviculture, the recommendations in the literature regarding the percentage of the residues that should be left in the field for soil recovery was followed. To estimate the energy productivity, a Sustainable Technical Coefficient (TC_S) was adopted (see Table 1). The Traditional Technical Coefficient (TC_T) represents the proportion of residues within the total yield (Coelho et al. 2015). For each of the crops and for wood, literature was found indicating how much could be used to maintain the integrity of the soil. For most of the sources, a percentage indicated by studies in Brazil, adequate for the tropical conditions, was adopted. Only for the case of coffee, as no specific literature was present, the general recommendation of

leaving 70% in the soil was assumed. Even though it may be considered a conservative value, the decision of removing a minor amount of residues aims to avoid solving one problem by creating another (soil degradation). The practice of conservation tillage has already proven effective for soil and environment conservation (Busari et al. 2018). In this paper, it was considered that the guarantee of supply for bioenergy production depends directly on soil productivity. A lower amount of organic matter in the soil can be more damaging to productivity than its excess. Thus, a more conservative coefficient was adopted in order to guarantee sustainability. Table 1 represents the values of TC_S used in the calculation.

Table 1
Traditional Technical Coefficient and Sustainable Technical Coefficient

Source	Type of residue	Traditional Technical Coefficient (TC_T)	Percentage left on the soil	Sustainable Technical Coefficient (TC_S)
Coffee	Husk	1.00	70%	**0.30**
Sugarcane	Straw	0.20	50%	**0.10**
Beans	Husk	1.16	60%	**0.45**
Manioc	Aerial	0.65	60%	**0.25**
Corn	Stover	1.68	60%	**0.65**
Eucalyptus	Primary processing	0.25	20%	**0.20**

The TC_T and TC_S for beans, manioc and corn were found on EPE (2014). For sugarcane, the coefficients adopted were from Dias et al. (2012). For the eucalyptus, less literature was found regarding the use of residues. A relevant portion of the residues correspond to the litter, which represents an important share on the nutrient cycling process. Foelkel (2016) recommends that the litter, leaves and small branches are indispensable for the maintenance of soil fertility. Therefore, only the residues from the harvests (primary processing) were considered. Specific data on the availability of each source and its proportion to be considered in the calculation can be seen in Table 2.

Table 2
Availability of each source and sustainable proportion considered for energy conversion

Source	Total yield (ton/year)	Sustainable Technical Coefficient(TC_S)	Available residues (ton/year)
Coffee	1,303,681	0.30	391,104
Sugarcane	71,080,882	0.10	7,108,088
Beans	569,466	0.45	256,260
Manioc	844,122	0.25	211,031
Corn	6,947,837	0.65	4,516,094
Wood	12,388,720	0.20	2,477,744

2.2. Application of formulas

To calculate the potential for energy production from biomass residues in the state of Minas Gerais, or the amount of energy that could be produced considering losses in the process, we applied different formulas to different sources. All the formulas were used by Coelho et al. (2012) (Coelho et al. 2012) for the Brazilian Bioenergy Atlas. These calculations provide an overview of how biomass energy is distributed in the state per source and are detailed presented in Ribeiro and Rode (2019).

All the calculations were made taking into consideration a viable technology: a cheap technology with low conversion efficiency (15%). Considering that investing in sustainable energy to improve people's lives is not necessarily an attractive business, even more in a context of economic crisis. Modern and expensive technology with a higher conversion coefficient would be unlikely to be financed.

2.3. Demand Calculation

The energy ladder from Coelho and Goldemberg (2013) was adopted to estimate the potential energy demand in the municipalities for two distinctive phases: (1) First phase: basic energy needs (lighting, cooking, and heating), which would necessitate about 50–100 kWh per person per year, (2) Second phase: productive uses (water pumping, irrigation, agricultural processes, heating, and cooking), which would necessitate about 500–1,000 kWh per person per year.

As presented by Coelho et al. (2015) and applied by Ribeiro and Rode (2019), low and high electricity requirements were calculated.

3. Results

From a total of 853 municipalities in the Minas Gerais state, only 49 didn’t reach the minimum production rate of 1,000 tonnes per year in the last agriculture census to integrate the analysis. As a result, the analysis focuses on 804 municipalities that reached the stipulated value.

3.1. Energy potential

Minas Gerais is a state where agriculture represents one of the strongest local activities, ranging from large scale monoculture farms to traditional family subsistence farming (IBGE 2009). The energy potential from annual crop residues (Fig. 1) had the highest results from all the sources, reaching values up to 60 MW with the yearly harvesting per municipality. The west sub-region, known as *Triângulo Mineiro*, had the best result, due to the dominance of modern large scale agribusiness in. This sub-region is the main producer of sugarcane and corn in the state (Bastos and Gomes 2011).

Standing out as the largest producer and exporter of coffee in Brazil, the state of Minas Gerais is responsible for more than 50% of the country's production. Even though the residues of coffee production alone show results varying from 0.1 to 1.5 MW (Fig. 2), the results are considerably lower than those of energy production from annual crop residues.

The state of Minas Gerais also has a strong silviculture sector. Having its origins with the stimulation of the steel and iron industries on the 1970s by the military dictatorship (1964–1985), the lack of coal to fire the sector was presented as an impediment. An incentive project was then created, where a 50% reduction on the taxes was given to private owners and companies that were willing to invest in silviculture (Calixto et al. 2009). This marked the beginning of the development of the eucalyptus sector in the country. By 2016, more than 2 million tonnes of wood was produced per year in Minas Gerais (SIDRA - IBGE 2015b). In the more productive areas, the estimation of the potential energy production from silviculture residues (Fig. 3) could reach values of up to 8 MW with the annual yearly harvest per municipality.

The combination of the values presented in the above generated scenario, where the most fruitful areas of the state would reach a value of the total sustainable technical potential for energy production of up to 65 MW with the yearly harvest per municipality (Fig. 4).

In total, within all the accessed sources, the annual crops show the highest potential at the state of Minas Gerais, reaching a total of 6,495 GWh/year. This reflects the consolidated agriculture industry present in the state, mainly in the western. The permanent crops have the smallest value: 259 GWh/year. Considering that the only permanent crop type accessed was coffee, the results are interesting. The silviculture potential shows a more distributed result, with no concentration in one specific region of the state and reaching a total of 1,409 GWh/year.

3.2. Demand vs. production

To evaluate if the sustainable energy potential could meet the local energy demand, the potential future energy demand for basic needs and productive uses was calculated and compared to the sustainable technical potential (Figs. 5 and 6).

The municipalities where the demand was met in the basic needs scenario, reach 79% of the total municipalities (Table 3) and 83% of the analyzed municipalities. Most of the places where the results were not sufficient represent large metropoles, with no space for agriculture and high demand for energy.

The large municipalities that could meet the energy demand in a productive use scenario are those with the greatest yield in the state. Many of them are at the west sub-region, where the agribusiness is concentrated and the highest GDP on the state is located.

Table 3
Synthesis of the results of demand vs. production.

		Basic Needs		Productive Uses	
Municipalities	**Sufficient**	670	78%	157	18%
	Not sufficient	134	16%	647	80%
	Not analyzed	49	6%	49	6%

4. Discussion

For the scenario of basic needs for the whole state, a surplus of 6,704 GWh/year was estimated. One possibility for optimization is the exportation of residues from regions with energy surplus to places where the agricultural and silviculture residues cannot cover the demand. Another option to be exploited is the transformation of the surplus into pellets: a dry, compact and small portion of biomass that is easily stored and transported. This alternative could be a solution to meet the demand of areas with lower residues and generate income for the places with additional residues. A Brazilian law resolution from 2015 (ANEEL 687/15) began to facilitate the process of decentralized energy production, regulating the distribution of micro and mini energy generation. Therefore, creating an ideal context for the development of small energy generation units.

According to the Brazilian Institute of Geography and Statistics (IBGE), Minas Gerais is the fourth biggest state in the country and the second largest in terms of the inhabitant numbers, with an estimated population of 20,869,101 inhabitants in 2016 (IBGE 2017a). From the 853 municipalities, 32 have large cities (more than 100 thousand inhabitants) and hold 45% of the state's population. Those populated municipalities have more capacity to increase the energy demand, while also having less area to produce agriculture and residues. These municipalities are responsible for 12% of the energy potential and, as it is calculated based on the population, 45% of the energy demand. This unbalanced relation means 11 of those 32 municipalities meet the demand on a basic needs scenario and only one on a productive uses scenario. Palmas et al. (2015) investigated the regional potential for the ideal renewable energy mix in Germany. Such kind of research has not been carried yet in Brazil and could figure as the next step on way of creation a sustainable energy system for Minas Gerais. As assed on this paper, biomass could figure as a supplier of 78% from the basic needs demand and 18% of the energy in a scenario of productive uses (Table 3). An ideal sustainable energy mix, including other sources such as solar and wind energy or even biomass from urban solid waste, could reduce the risk of energy shortages and blackouts and contribute to a clean and safe energy matrix.

It is important to remark that the demand calculation is based on the essential needs of a household, so the amount of energy estimated does not reflect the modern patterns of energy consumption. The energy that comes from residues could be directed to the low-income population, focusing on the rural area where it is produced and on improving locally produced goods, as well as raise its attractiveness for new local business (Venghaus and Acosta 2018). Investments in education and infrastructure can come from a more accessible energy system, as well as better possibilities for savings, entrepreneurism and new agricultural activities. The impact of energy generation is not purely related to the increment of income. It could also have a significant role in the improvement of education and health possibilities, as well as gender equality, considering that the improvement of electricity access usually has a larger effect on female employment (Cook 2011). Considering the environmental and social risks involved with new hydropower projects (Ferreira et al. 2014), the development of technologies and programs, that support the propagation of the use of biomass residues for energy production, can play an important role on future sustainable development in Brazil.

Among the production means existing in the state, family farming is the main responsible for the food supply for the state population. Characterized by small properties, managed essentially by the family, it presents a larger amount of properties (79% of the farms on the state (IBGE 2017b)), with greater work and income generation per cultivated area (Abramovay 1997). Those small farmers are commonly organized in cooperatives production systems and associations, in order to increase the competitiveness of their product and their market insertion (Costa et al. 2015). Being a model that is already applied by those farmers for other purposes, the organization in cooperatives of biomass energy production from their crop residues could optimize the logistics for collection and processing of this residue, as well as the distribution of the energy generated.

One concept that could be applied for the development of energy production through biomass residues is the so-called Social Technology. According to Dagnino (2014), a Social Technology is any method, process, product or technique, shaped to solve some type of social problem that meets the necessities of simplicity, low cost, easy applicability, replicability and proven social impact. The creation of a model for energy production, that works for lower income communities and that is simple to replicate with minor adaptations could improve the local and regional development without generating impacts on the environment and improve the local economy.

5. Conclusions

This paper aimed to explore the alternatives for renewable energy generation in Brazil, investigating specifically the case of residual biomass from agriculture and silviculture. The chosen study area was the state of Minas Gerais, a region that was pointed out by previous researches as promising for this type of assessment. A Sustainable Technical Coefficient was developed, taking into consideration that part of the residues would be let on the soil with the objective of maintaining the nutrient cycling and soil health, ensuring the sustainability in the long term. The technology chosen for the calculations has low efficiency in energy conversion. Being a cheaper option, easily found in the national market, it was selected for

being the most viable. The energy demand was estimated and compared with the energy potential results.

In a country where hydro energy represents not only the highest share of the energy matrix but also a fragile energy source, the results of this study reveal a promising new path. For the state Minas Gerais, with its tradition of agriculture, 78% of the municipalities could have their basic energy needs met by residues of crops and silviculture production. When more elaborated uses are considered, there is a drop where 18% of the municipalities would be able to be self-sufficient in energy supply. Even with a significant reduction on the percentage, this would relieve pressures placed on the construction of new hydroelectric plants, which have substantial negative impacts on the environment and in the way of life of the communities on the surroundings of the flooded areas. A cooperative production system among rural producers is also presented as an alternative to reduce production costs and may allow the partial improvement of agricultural raw material, adding value to the final product. An energy mix where other renewable energy sources are considered can also increase the chances of success of an enterprise focused on renewable energy.

Since 2015, Brazil has faced an economic downturn that tends to decrease the attractiveness of an investment. Other relevant aspects for consideration, are the lack of policies that encourage the deployment of new renewable energies and the questionable environmental agenda adopted by the elected government in 2018. The results obtained here can be used to empower the local population or stakeholders, as a base to seek for renewable energy projects, creating the ground for changes in the country's energy system.

It should be noted that calculations regarding collection logistics, transport of materials, purchase, installation, and operation of a power generating unit and training, were not addressed in this paper and should be taken in consideration in future studies.

Declarations

• Ethics approval and consent to participate:

• Not applicable.

• Consent for publication:

• Not applicable.

• Availability of data and material:

• The datasets analyzed during the current study are available in the SIDRA (Brazilian Institute of Statistic and Geography Automatic Recovery System) repository, at https://sidra.ibge.gov.br. The datasets generated during the current study are available from the author on reasonable request.

• **Competing interests:**

• Not applicable.

• Funding:

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• Authors' contributions:

Not applicable.

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Figures

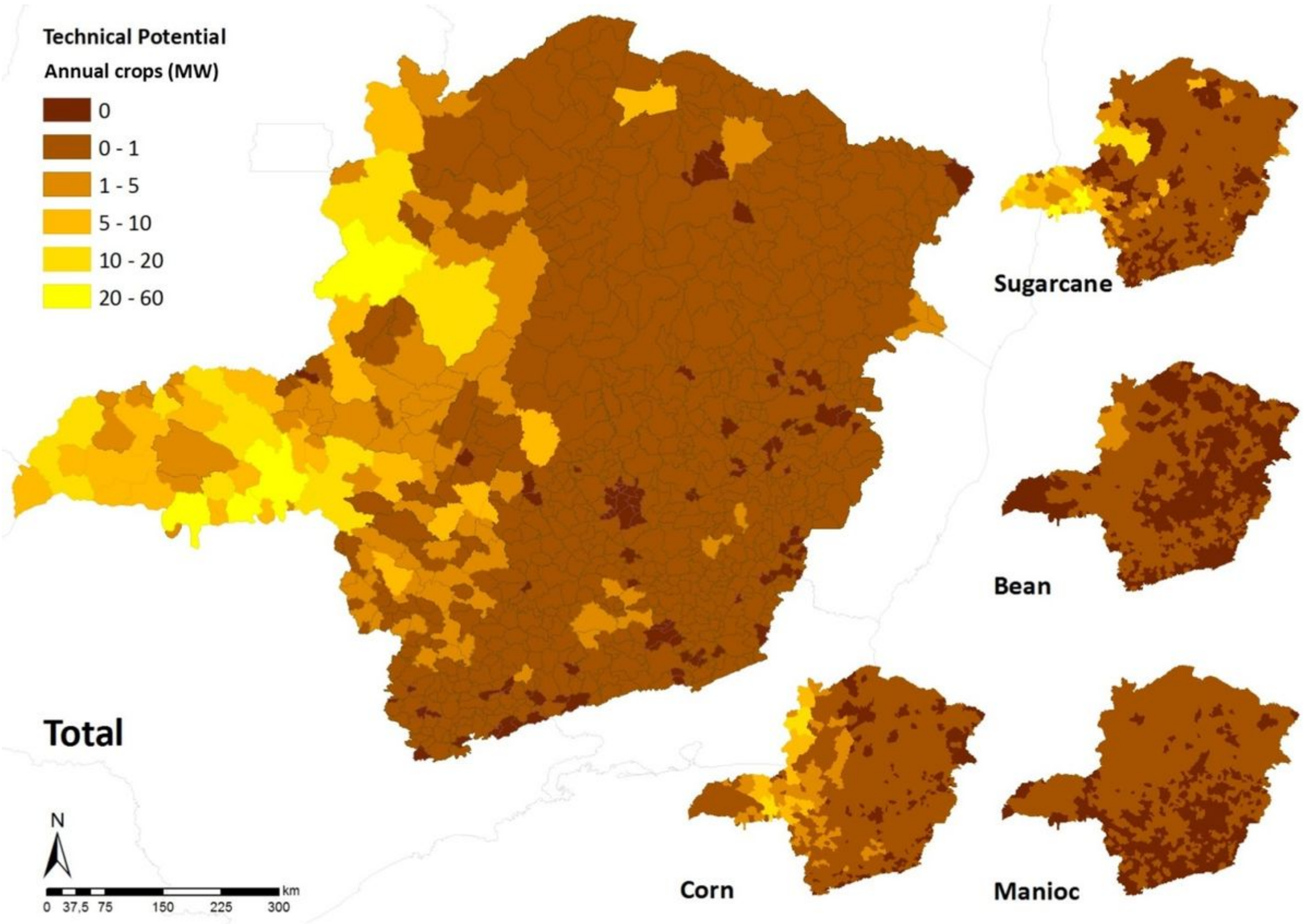

Figure 1

Sustainable technical potential of energy production from annual crop residues with the yearly harvest per municipality.

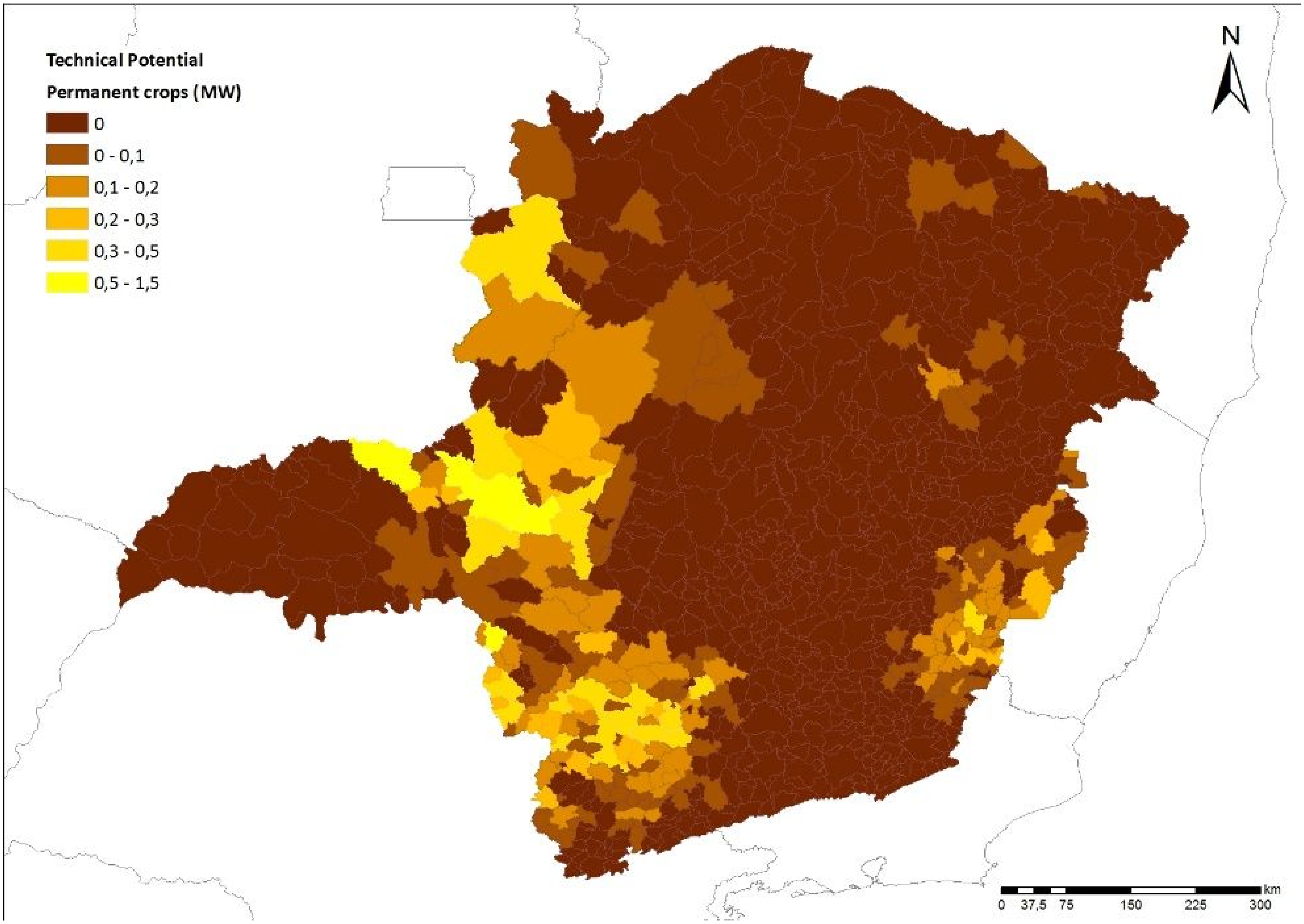

Figure 2

Sustainable technical potential of energy production from coffee residues with the yearly harvest per municipality.

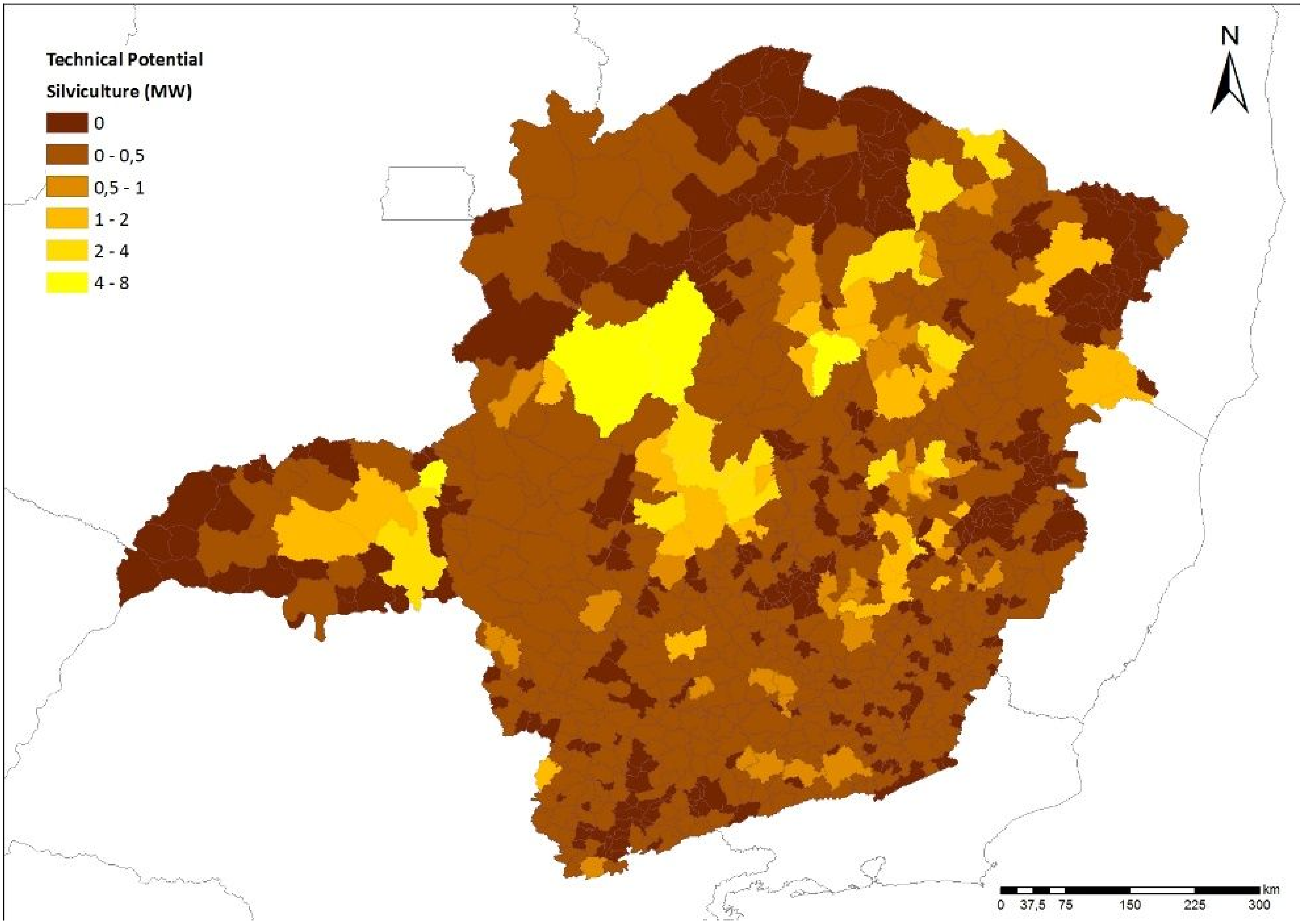

Figure 3

Sustainable technical potential of energy production from silviculture residues with the yearly harvesting per municipality.

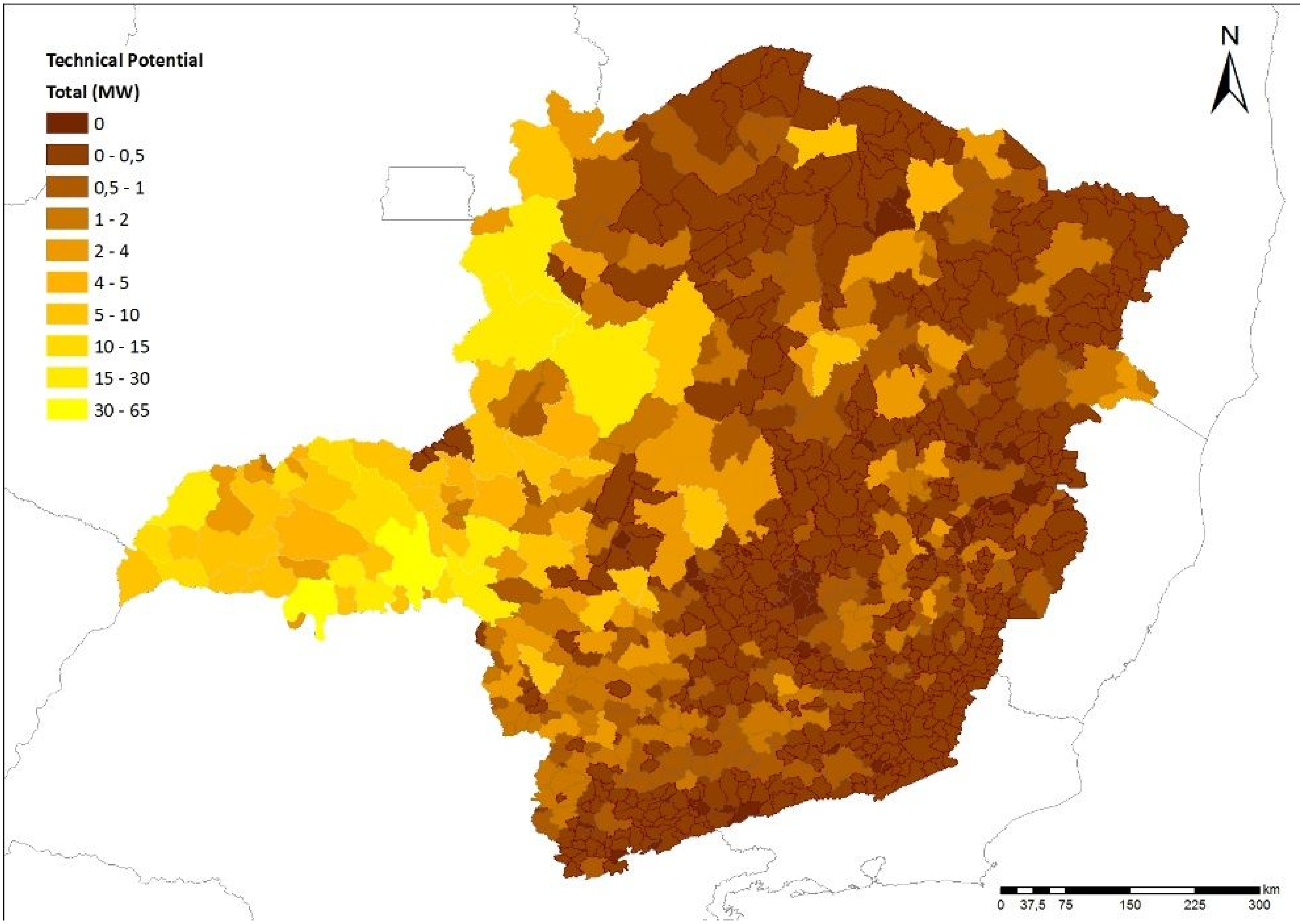

Figure 4

Sustainable technical potential of energy production from all agriculture residues with the yearly harvest per municipality.

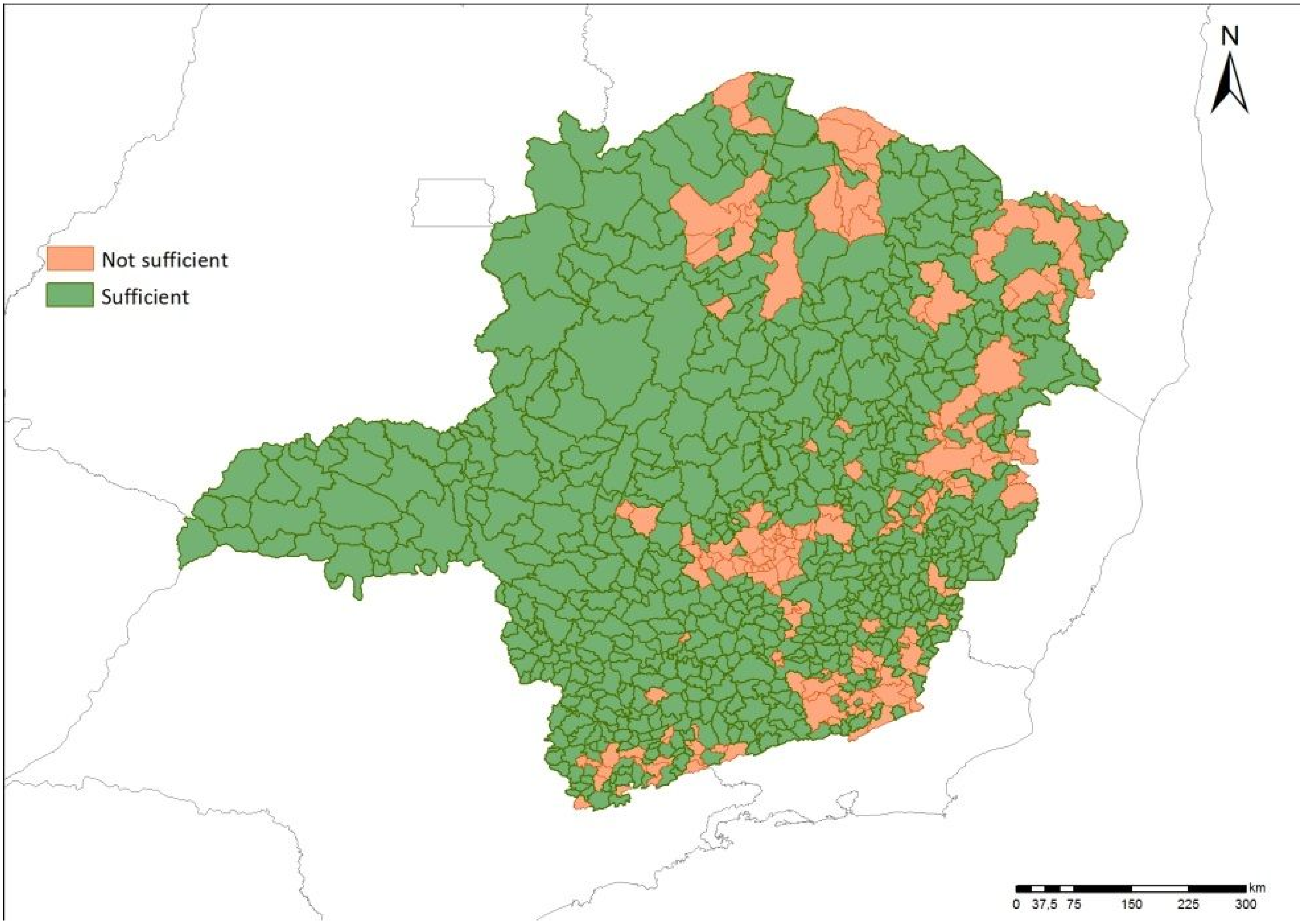

Figure 5

Demand vs. production in a scenario of basic needs.

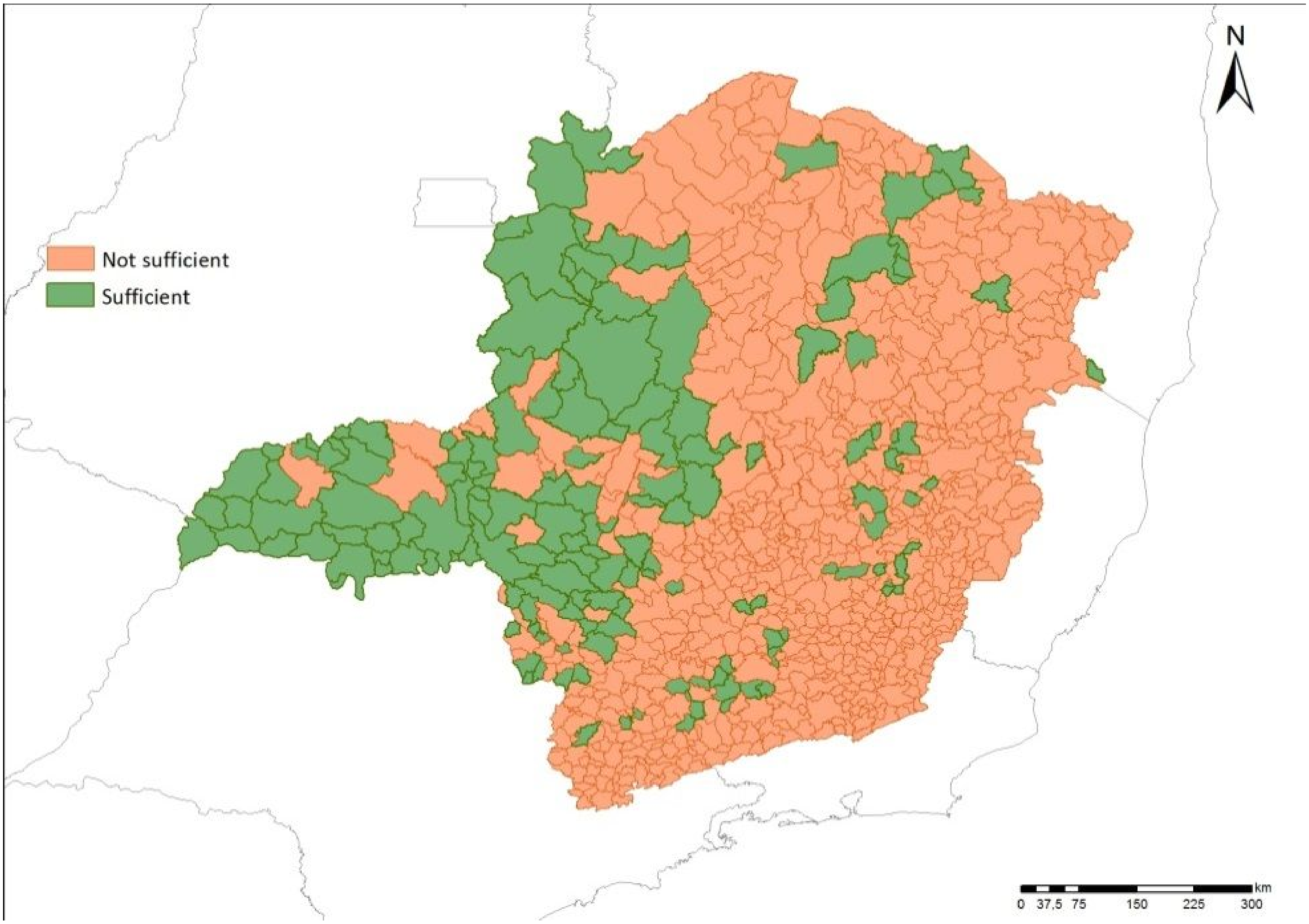

Figure 6

Demand vs. production in a scenario of productive uses.

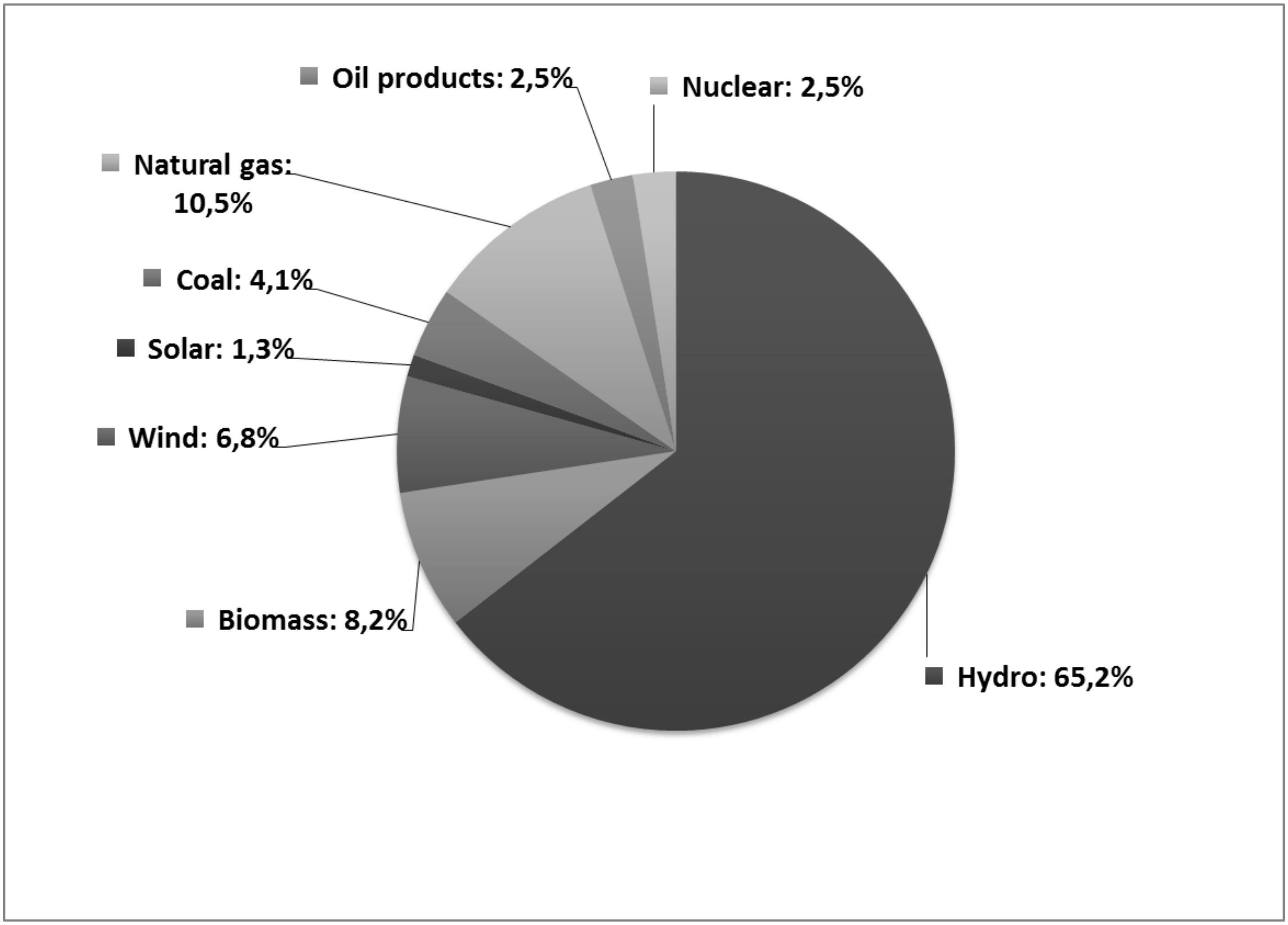

Figure 7

Domestic electric supply by source [11]