Economic Impacts of Bioelectricity from Forest Biomass when Forest Producers have Comparative Advantage: the case of Brazil[*]

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Summary

Forest biomass has been used as an energy source since the begging of human king. Compared with other countries, Brazil has a natural advantage to produce commercial forests. The bioelectricity in the country, however, derive mostly from sugarcane industry. This study aimed to understand the impacts and pathways of an eventual expansion of forest plantations dedicated to electricity production on the domestic economy, especially on the forestry, energy and other competitors' sectors. We employ a dynamic-recursive computable general equilibrium model of world economy to project alternative scenarios about forest bioenergy expansion in Brazil. The results suggest that the increase in forest biomass for electric power generation is highly dependent on governmental incentives and technological advances. A consistent participation of the forest biomass in the grid has almost no economic impacts on other sectors using forest based inputs, such as pulp and paper and iron and steel industries, neither on land use competitor sectors, like the agricultural sector. Even with very high public incentives to increase forest biomass, the impacts on GDP are negligible. Land use dynamics from larger increase in planted forest will not influence deforestation rates of native vegetation. Therefore, although the upscaling of forest biomass to bioelectricity in Brazil has very low negative impacts on other economic sectors, GDP or land use dynamics, only governmental incentives will ensure the growth and strengthening of forest bioelectricity as an energy source in the country.

1. INTRODUCTION

From the early days of humanity, wood presents itself as a source of energy, and is still important in many societies and regions of the planet. However, with the discovery of oil, this one has become the main energy base of most developed countries.

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The energy use of biomass for human evolution should be considered fundamental, and its own means of acquisition and use have been developed jointly, from the wood used for cooking and heating, to the modern forest-farming production practices and industry, of biofuels use for driving force generation, heat and electricity (EMPRESA DE PESQUISA ENERGÉTICA – EPE, 2016).

Currently, the fact that the energy matrix is based on fossil, non-renewable and harmful to the environment fuels, has led many countries to evaluate the search for and use of alternative and renewable energy sources (BRITO, 2007).

Brazil is in a relatively privileged position compared to other countries, due to the predominance of renewable sources in the electric power production matrix (SERATTO, 2010). The data from the National Energy Balance (BEN) show that the current installed capacity of production of renewable energy sources represents most of the domestic energy supply capacity, with hydroelectricity as the main responsible, with 65.8% of participation, and biomass sources representing 8.5% (EPE, 2017).

Numerous appropriate attributes are found in the country, such as geographic and climatic, agricultural and economic conditions, to develop and benefit from the technologies used in the production of biomass for energy purposes and thus to supply both the internal and external markets (NAIME et al. 2003). The country is considered an interesting candidate to lead the production of biomass, including liquid biofuels (biodiesel and ethanol) in the world scenario (RASGA, 2013).

Until recently, it was found that many forms of biomass were not considered as an energy source, leaving much of the product in the field and part of it being considered as organic fertilizer, trying to justify latent energy waste (RASGA, 2013).

The energy usefulness of biomass in its diverse forms presents benefits, such as ensuring a greater enjoyment of available resources, adding value and optimizing the agricultural production process and minimizing impacts resulting from the generation and disposal of waste in the environment (EPE, 2016).

Another advantage of the use of biomass is the fact that it is a renewable energy and it contributes to the mitigation of climate change. In the case of planted biomasses, such as wood and sugarcane, it is considered that the CO_2 emitted in the combustion is equal to that absorbed from the atmosphere in the process of photosynthesis performed by the plant. In this way, a low or almost null balance of CO_2 emission is attributed (EPE, 2016).

In Brazil, bioelectricity is mainly obtained through two industrial segments, the sugar-ethanol and pulp and paper, this one on a smaller scale. However, in the last decades, these sectors have expanded, and their units have been modernizing. With the modernization of these units, there is a greater efficiency in the processes and in the energetic use of the industrial processes, generating greater surpluses of bioelectricity, and consequently, a complementation and important participation in the diversification of the electric energy supply in Brazil. Additionally, the use of firewood from planted forests for electricity generation has been increasing and contributing to this diversification (EPE, 2016).

According to Rasga (2013), there is a shortage in the number of broader public incentive policies, mainly involving biomasses, discouraging the use of these sources, for example, for the exchange of heat generation systems by consumers. The incentives should be applied from the exemption or reduction of taxes on the equipment for the burning and/or production of these biomasses, even on the product itself.

Considering Brazil's potential and capacity to produce low-cost and high-efficiency forest biomass, as well as the growing need to replace fossil energy sources for renewables, what would be the impacts and possible trajectories of the expansion of the use of this forest biomass for production of energy for Brazil? Would the production of forest biomass for electricity generation jeopardize the supply of this raw material to the industrial sectors that use it more intensively?

The goal of this study is to investigate the possible impacts generated using wood from forest plantations for energy generation in other segments of the Brazilian forestry sector, such as the pulp and paper segment, wood panels, laminated, sawed and compensated floors, and steel to charcoal. More specifically, we intend to verify if the volume of forest biomass will be enough to meet the demands of these different forest segments and, if there is competition between them, to analyze which segment would have greater use of the supply and how these productive processes would be developed in Brazil.

2. LITERATURE REVIEW

2.1. Energetic Uses of Forestry Biomass

The use of wood for energy purposes is probably one of the oldest practices of mankind, and even today, among all possible uses of biomass, energy generation is still one of the most expressive. This use is marked by three great moments: the first remote to the discovery of the fire, when it played a decisive role for the development of humanity; the second marked by the industrial revolution, whereby it altered the patterns of consumption and the global economic dynamics of the time; and the third, more recent, marked by the competition with other energy sources, mainly fossil fuels, extremely competitive to accompany the development spurt of the last decades and the intense demand for industrialized products (BRITO; BARRICHELO, 1979; COUTO et al., 2004).

Even in the face of competition from nonrenewable energy sources, forest biomass energy is extremely relevant in some countries and specific economy sectors. This is due to the presence of characteristics that allow more rustic uses, such as direct burning of wood in the form of firewood or charcoal, uses tied to other industrial processes, through the use of waste, and even more advanced technological processes, such as the use of essential oils, tar and firewood acid (COUTO et al., 2002, MIRANDA, 2015, SOARES et al., 2006).

In the Brazilian context, wood still represented the country’s main energy source until 1972, losing its lead to the use of energy derived from oil the following year. This energy source remained a few years in the spotlight, because with the oil crisis, which was still in the 70’s, a series of government policies began to encourage the use of renewable energy sources. Because of the results of a policy group, hydroelectric energy took the first position as early as 1978 and the use of biomass and bagasse energy also consolidated in the country, being the most famous program of that time called Pro-Alcohol (BRITO, 1990).

It can be noted from the literature that the theme related to the production of energy through forest biomass has been discussed for years. According to Brito and Barrichelo (1979), Brazil presents several competitive advantages for the use of forest biomass in energy production, among them: forestry vocation derived from the ideal edaphoclimatic conditions and extensive areas of forest implantation for industrial purposes; technologies that allow the development of high productivity forests, as well as above those of other countries with a forestry tradition; experience in special techniques for the management of energy forests; and demand of different forest products and by-products, making this a versatile investment.

The Brazilian Tree Industry – IBÁ highlights that the energy forests in Brazil have the potential to supply thermoelectric power plants in a competitive way, collaborating with the decentralization of the energy production system, besides bringing the discussion of the role of these forests in reducing the pressure for deforestation of native vegetation (INDÚSTRIA BRASILEIRA DE ÁRVORES – IBÁ, 2016)

Currently, according to the most recent data available in the National Energy Balance (BEN), the internal supply of electricity comes mostly from the hydroelectric matrix, followed by natural gas and thirdly from biomass. Biomass energy already represents 8.2% of the available domestic supply, of which 77.6% comes from sugarcane bagasse and 22.4% from planted forests (EPE, 2017).

To better understand the importance of the use of biomass energy, it is essential to pay attention to the definition of the concept related to biomass seen in the literature. The American Council on Renewable Energy – ACORE, defined the following concept:

> Biomass is any organic material, including:
> - Raw material of the forest deburring process where: they are by-products of the forest process (wood, cellulose), industrial or agricultural and are harvested according to the laws of forest management;
> - waste materials, including: crop residues; other vegetative materials and mineral oils (including wood waste); animal waste and by-products (including animal fats, oils, greases and manures); and the fraction of biogenic materials segregated, food waste, garden waste and waste water biosolids treatment plant;

> - Plant materials including: grains; other agricultural products; trees harvested in accordance with forest management laws, rules and regulations; other plants; and algae, aquatic plants and derivatives (including oils). (ASSOCIAÇÃO BRASILEIRA DAS INDÚSTRIAS DE BIOMASSA E ENERGIA RENOVÁVEL - BRAZILIAN ASSOCIATION OF BIOMASS AND RENEWABLE ENERGY INDUSTRIES – ABIB, 2012, p.10).

In the national context, the concept of forest and industrial biomass is presented as "biofuels derived from forest and industrial resources, their products and by-products, which basically include wood biomass, produced in a sustainable way from cultivated forests and native forests, or that originated in activities that process or use wood for non-energy purposes, especially the pulp and paper industry, the furniture industry and sawmills" (ABIB, 2015).

Forest biomass can be obtained and used in three states: (i) solid biomass derived from products and solid waste from agroforestry or related industries, such as firewood, coal, briquettes and pallets; (ii) liquid biomass through biofuels, liqueurs and oils; and (iii) gas biomass, by means of biogas generated as industrial effluent or gasification processes. Each form is created according to the specific physical-chemical actions, such as roasting in the case of coal and briquetting in the case of briquette, or a liquefaction for the synthesis of the firewood liquid and a gasification for the conversion of liquid in solid and liquid energy gas (ABIB, 2015; COUTO et al., 2004).

The biomass forms that deserve special attention because of their importance in the national context are charcoal, briquettes and bioethanol. Charcoal in Brazil, besides being still used in some regions for obtaining residential and urban energy, has great relevance in several segments of the industry, mainly steel, metallurgy and cement. In the steel industry, a quarter of the production of pig iron and half the production of ferroalloy is based on charcoal (BRITO, 1990; ESCOBAR; COELHO, 2015).

The remarkable versatility of the use of forest biomass led to an increase in the participation of this source in the Brazilian energy matrix. The biomass to produce electric energy is more recent than the other uses, and its exploitation was fomented by the supply crisis of 1999, which resulted in the famous "blackout" of 2001. Since then, innovative public policies and instruments were developed and, although initially the focus was on sugarcane agroindustry, it is now planned to complement this source to solve problems, such as the seasonality of sugarcane cultivation and the increase of agroindustry energy surplus (COUTO et al., 2004; SERATTO, 2010).

Data from the National Electric Energy Agency show that the production and commercialization of energy from forest biomass has not yet become a reality in Brazil, the majority of which is linked to the use of black liquor in the pulp and paper industry, which represents 16.4% of the total capacity of biomass-fueled plants and most of the energy consumed by the industry itself (67%). However, the trend is an increasing demand for generation of thermal and electrical energy through forests, as energy-intensive industries sectors develop, new technologies emerge to a more efficient use, and incentives and favorable public policies are implemented (ESCOBAR; COELHO, 2015; SERATTO, 2010; IBÁ, 2016).

2.2. Economic Viability and Incentives

There are still few studies explicitly addressing economic viability and relative indicators related to the national energy production through forest biomass. Most of the existing studies address the viability of energy production through solid wastes (ALMEIDA, 2016, DAL FARRA, 2004, ESCOBAR, COELHO, 2015, MIRANDA, 2015), or other biomass energy sources, mainly sugarcane bagasse (ANDRADE, 2016; MALUF, 2014).

Among the studies aligned with the questions of this study is Seratto (2010), who evaluated the feasibility of a project of production of forest biomass for electric energy to be offered in the off-season of sugarcane, when there is no bagasse enough for energy production. When analyzing indicators such as rate of return, payback and net present value (NPV), the analyses showed that in that specific situation an attractive internal rate of return (IRR) (10.7%) was not obtained. However, there was a considerable effect of the average radius between the areas for energy production and cultivation (inversely proportional) and high sensitivity to the variation of electric energy prices, the latter being the most significant parameters for determining viability.

Also, in the literature is the work of Miranda (2015), in which the use of forest biomass was used in comparison with other fuels: natural gas, liquefied petroleum gas, fuel oil, diesel oil, wood chip and wood. It was found that the cost of the ton of steam using the chip was at least 34% lower than the other sources evaluated. In addition to the competitive cost, high productivity, long-term supply and regional scope were highlighted as weaknesses in marketing by volume, logistics, low concentration of energy and, mainly, political and bureaucratic difficulties due to lack of incentives.

Another important study is that of Rasga (2013), which highlights the main economic and financial aspects that may influence the substitution of the use of BPF-A1 oil by pellets and compares with other biomass sources such as briquette, chip and firewood. Fundamental methods such as payback, net present value and internal rate of return were used to analyze the financial viability, as well as a sensitivity analysis of the main factors studied. The study shows that wood pellets are more expensive than other forms of biomass (chip, briquette, and firewood), but are cheaper than fossil fuels (BPF-A1 oil, natural gas and liquefied petroleum gas) and the electric energy for the two scenarios analyzed by the author (conservative scenario and intermediate scenario).

Seratto (2010) raised some of these incentive policies for the energetic use of forest biomass in Brazil, highlighting the 2002 Alternative Power Source Incentives Program (PROINFA), credit lines of the National Bank for Economic and Social Development (BNDES), and the government’s strategies for the purchase of energy from these sources by Companhia Centrais Elétricas Brasileiras S.A. Also noteworthy are the legal advances that allowed free access to the transmission and distribution networks and improvement of the calculation methodology for remuneration, enabling the participation in the supply auctions of the Brazilian regulated market.

A complementary study in the line of incentives, held by the Center for Sustainability Studies (GVces, 2016), explores existing financing mechanisms for the implementation of renewable energy projects and their main barriers. According to other sources, the main financial products are those enabled by the BNDES and others supported by international funds, such as the Inter-American Development Bank (IDB) and the Andean Development Cooperation (CAF). The same study analyzes the main barriers found in the advance of the adoption of renewable energy in the country. The major hurdles of high impact and direct influence faced in the expansion of renewable energies are related to regulatory and administrative difficulties, subsidy and competition with other sources and investment costs. It is interesting to note that, even as a barrier of high impact, but of indirect influence, the government's own development strategies were identified.

In relation to the policies recently published by the Brazilian Government, the basic document elaborating the implementation strategies of the NDC explicitly mentions the incentives and barriers to the adoption of the use of forest biomass for energy generation. One of the main promotion measures is the establishment of public incentive policies through the National Energy Planning prepared by the Ministry of Mines and Energy. The main barrier identified in the document is the recognition of the low competitiveness of biomass in energy auctions, due to the waiting period, consolidated forest base required and cost of acquisition in the market. In this way, the document itself proposes a policy of creating incentives for biomass in renewable energy auctions (EPE, 2016).

In this way, with the growing demand for renewable energy, due to international policies, constant modernization of the Brazilian forest industry, seasonality of other agricultural industries generating energy and evolution of public policies and incentives for energy production from forest biomass, it is of great urgency an evaluation of the possible economic impacts of the production of this source of energy for commercialization, mainly in competition with other products and by-products of the industry itself, or with other sources of biomass for energy production.

3. METHODOLOGY

In order to investigate the possible impacts of increased use of wood from forest plantations for energy generation in other sectors, such as the other segments of the Brazilian forestry sector that use this supply as the main raw material, such as pulp and paper, wood paneling, laminate flooring, sawn and plywood and steel to charcoal, it was used dynamic-recursive model of computable general balance called Economic Projection and Policy Analysis – EPPA (CHEN et al, 2017), developed specifically for the study of energy and climate policies.

Bellow, the concepts related to the Computable General Balance Models – EGC and the EPPA model, based on the works of Chen et al. (2017) and Gurgel (2011), are described briefly.

Searching to portray the economy (real side) of one or more regions and countries, computable general balance models (EGC) contribute to the characterization of general balance effects caused by exogenous changes, which are not initially identified by their complexity or relations unexpected and not obvious (PIERMARTINI; TEH, 2005). The evaluation of the results of this class of models enables to identify relations between sectors and economic agents that would be difficult to find in theoretical or analytical models, which require simplification in the number of agents and economic relations. Additionally, the analysis of simulated results by this class of models presents some advantages such as, for example, the visualization of the directions and magnitudes related to exogenous shocks and the comparison of alternative scenarios.

Shoven and Whalley (1998) highlighted the general balance models as a characterization of the relations between the various agents who seek each its optimization and relate through the goods and factor markets. The balance in these models occurs when the various endogenous variables (prices and quantities) adjust in such a way that agents cannot improve their situation by changing their behavior. In this way, supply and demand become equivalent in all markets, companies under constant returns of scale earn normal profits and agents' expenses adjust to their revenues.

Through the circular flow of goods and services in the economy, it is possible to portray the general balance models (Figure 1), in which consumers proffer capital and labor (primary factors of production) to the productive sectors, which in turn proffer goods and services to consumers. Due to the available capital and labor provided by consumers arising from the productive sectors, it is subject to the receipt of payments (income), and with these funds received, the goods and services are consumed by consumer spending (PALTSEV et al., 2005).

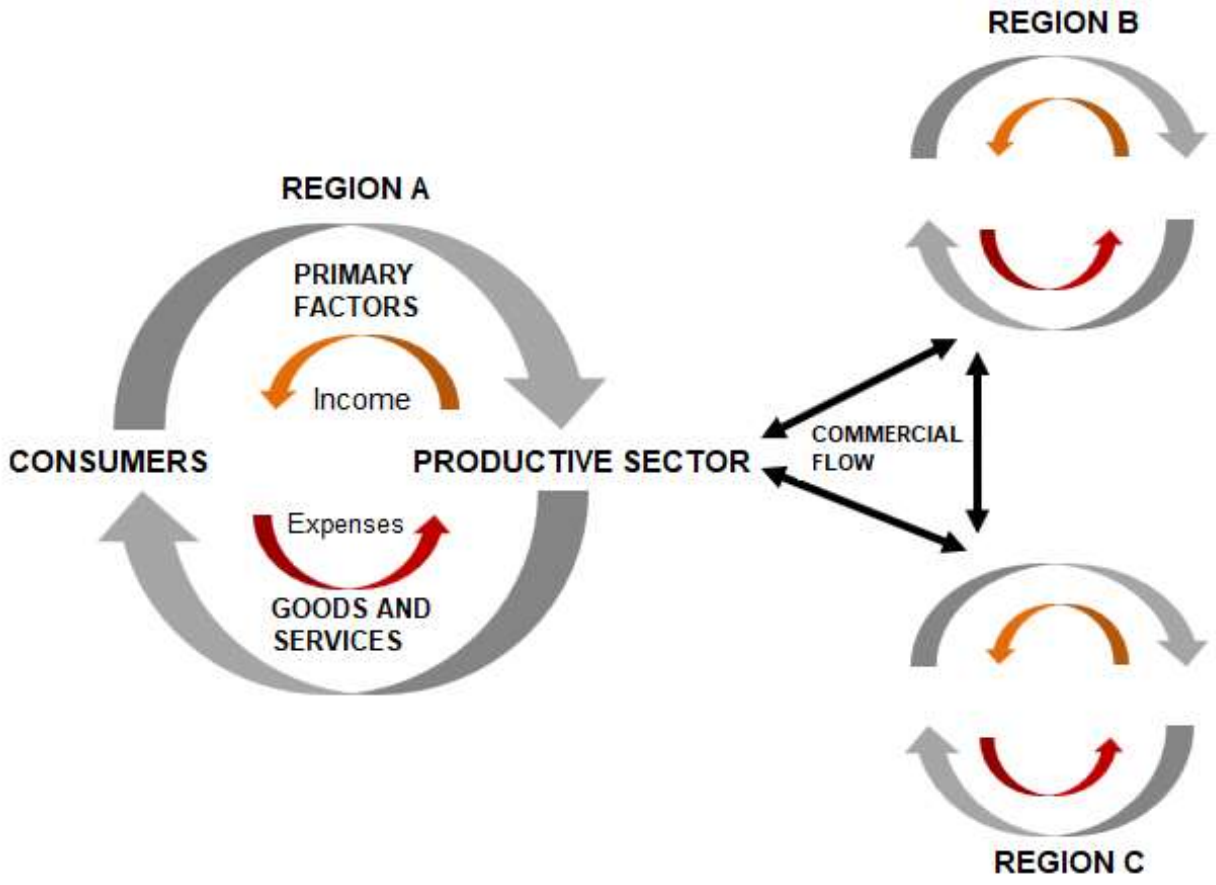

Figure 1 – Circular flow of goods and services.
Source: Adapted from Chen et al., 2017, p.5.

Some models also explicitly represent the government, but their role in the circular flow is often considered passive, since resources received through taxes are reintroduced into the economy through public spending (consumption) and transfers to households. The models can also be characterized as single region or multiregional, ranging according to the commercial relations existing between the different regions and/or countries, which may be endogenous or exogenous.

Regarding the balance in the circular flow of goods and services in the economy, this is represented by the conservation of product and value. The conservation of the product happens when the economy is not in balance and conservation value reflects the accounting principle of balanced budget that for each activity in the economy, the value of the expenditure must be balanced by income value (WING, 2004) ****

According to Sadoulet and Janvry (1995), the computable general balance model reproduces the conditions of market balance through a system of simultaneous equations. This method makes use of general balance economic theory as an operational tool in the empirical orientations on issues related to trade flows, market economies, technological change, resource allocation, shocks, among others.

When the expected result refers to the generation of general balance effects in the economy from political measures or exogenous shocks, the use of computable general balance models is justified (MALUF, 2014). An example is the case of the shock from increased use of wood from forest plantations for energy generation in other segments of the Brazilian forestry sector that use forest biomass as the main raw material.

The EPPA model was developed by the Massachusetts Institute of Technology (MIT Joint Program on the Science and Policy of Global Change) and is widely used in the study of aspects related to energy, agriculture, land use and climate policies (CHEN et al., 2017). It is a multiregional and multisectoral model and can be described as a dynamic recursive computable general balance (CGE) model. It finds the economic balance for a certain period and makes use of the results of this balance as the initial condition for the subsequent period, repeating this order of operations until it reaches the final projection date. The model is presented at intervals of five years and the time horizon can extend to simulations until the year 2100 (CHEN et al., 2017; PALTSEV et al., 2005).

The construction of the model is based on a class of mathematical problems that encompasses optimization (linear and non-linear) and employs the syntax of the Modeling Programming System for General Balance (MPSGE), developed by Rutherford (1999), assuming the identity of the model as a mixed complementarity problem – MCP. The MPSGE represents a set of algebraic equations that characterize the conditions of null economic profit for the production, balance between supply and demand in the markets of goods and factors of production and balance between income and expenses of the consumers and is implemented in the programming language General Algebraic Modeling System – GAMS (BROOKE et al., 1998).

Economic data feed the model, mainly the social contract and supply-product matrixes, which translate the economic structures of the regions from the Global Trade Analysis Project (GTAP), a consistent database on consumption, production and bilateral trade flows, both from the macroeconomic and microeconomic points of view for a large set of regions and countries of the world (DIMARANAN, MCDOUGALL, 2002, HERTEL, 1997). The balance sheets provided by the International Energy Agency work as a basis for data on the production and use of energy in physical units. The United States Environmental Protection Agency provides inventories with statistics on greenhouse gases (carbon dioxide – CO_2, sulfur hexafluoride – SF_6, hydrofluorocarbons – HFCs, methane – CH_4, nitrous oxide – N_2O and perfluorocarbons – PFCs). The information on other urban pollutants (ammonia – NH_3, organic carbon – OC, carbon black – BC, non-methane volatile organic compounds – VOC, sulfur dioxide – SO_2, nitrogen oxides – NOx and carbon monoxide – CO) were provided by the Emission Database for Global Atmospheric Research (EDGAR), developed by Olivier and Berdowski (2001).

For the present study, the EPPA5 version of the model, calibrated for the base year of 2004, was used. Endogenous simulations were performed every five years starting in 2005.

4. RESULTS

To meet the goals of this study, which proposes to investigate the possible competition of wood energy generation in the country, we simulated eight scenarios divided into a reference scenario and two more groups, covering the generation of electric energy from supplies from forest biomass and the regular production of the Brazilian forest sector:

a. Reference scenario (denominated BAU – business as usual): the economic indicators are evaluated considering the regular production of the forestry sector, but as if the generation of electric energy through the burning of the wood was not feasible over time, this means, BAU represents the path of the economy projected by the EPPA model if it continues under the same dynamic that determines it today, excluding the possibility of implantation of the technology of electric energy generation through the forest biomass;

b. 1st group – Incentive scenarios (low, medium and high): this group is contemplated by three scenarios and the viability of the generation of energy from the burning of the wood stimulated by public incentives in three scales (low incentive, medium incentive and high incentive) in the period between 2015 and 2050. The scenarios were named as follows:

- G1 low: scenario with low subsidy level with an average value of 18%;
- G1 medium: scenario with intermediate level of subsidy with average value of 36%;
- G1 high: scenario with high level of subsidy with average value of 54%;

c. 2nd group – Incentive scenarios (null, low, medium and high) with a learning curve of moderate cost reduction: this group is contemplated by four scenarios and the feasibility of generating energy from the burning of wood with reduced costs over time (given by the introduction of a learning curve with a reduction value of 78% in 2050) and stimulated by public incentives at different levels (null incentive, low incentive, medium incentive and high incentive) in the period between 2015 to 2050. The scenarios were named as follows:

- G2_null: scenario with learning curve and without subsidy;
- G2_ low: scenario with learning curve and low level of subsidy with average value of 18%;
- G2_medium: scenario with learning curve and intermediate level of subsidy with average value of 36%;
- G2_high: scenario with learning curve and high level of subsidy with average value of 54%.

The simulations of all the scenarios already detailed above resulted in several results for the period from 2015 to 2050, which were analyzed, compared and presented in this section. The results were grouped into four variables: sectoral activity index, energy source participation in the supply of electricity, gross domestic product (GDP) and land use.

4.1. Sectorial Activity Index

The first result of interest in this study is related to the activity index for the various sectors of the economy. The model generates data for different sectors, but more emphasis was given to the most relevant sectors in relation to the production and use of wood, such as forestry, agricultural, chemical (including pulp and paper) and steel.

4.1.1. Forestry Sector

The model projects the need for growth of the forest sector to meet this new demand to produce forest biomass for energy generation, ranging with the degree of public investment.

In the reference scenario, the sectoral activity index increases from 1.00 to 3.50 in 2050, which means that this sector would expand by 250% up to that year, due to the accumulated growth of the economy during this time and the demands of forest products resulting from such growth. In the scenarios of group 1, the scenario with low subsidy level behaves like the reference scenario, with a growth of 264% over the 35 years. This demonstrates that the low government subsidy to forest-based electricity is not enough to encourage the growth of this new technological demand. In the other two scenarios, with medium and high subsidy, the growth line reached 207.7% and 320.5% more than the reference scenario for 2050, respectively (Figure [ ]).

The scenarios of group 2 behaved in a similar way to those of the first group, but with even higher values of activity index due to the introduction of the learning curve, responsible for reducing costs over time. The simulation without any kind of incentive reacts very close to the reference scenario until 2035, with a growth of 111.5% in relation to the reference scenario in the year 2050. Therefore, the reduction of costs in the production of forest bioelectricity begins to do effect and increase the production of the forest sector as a raw material from 2035. The following three simulations (low incentive, medium incentive and high incentive) react in equivalent manner at different levels, with the tendency for the activity index of this sector to be high during the analyzed years.

The low subsidy scenario of this second group presented a growth superior to the same scenario of the first group, having a growth value of 229% in relation to the reference scenario. This difference is mainly determined by the increase in the learning curve, this means, the reduction of costs in the production and sale of biomass for energy production assists in the development and growth of forest activity. This can be further corroborated by the high growth rates of the other two scenarios of this second group (medium and high investment) compared to the reference scenario in 2050, being 329.9% and 441%, respectively (Figure [ ]).

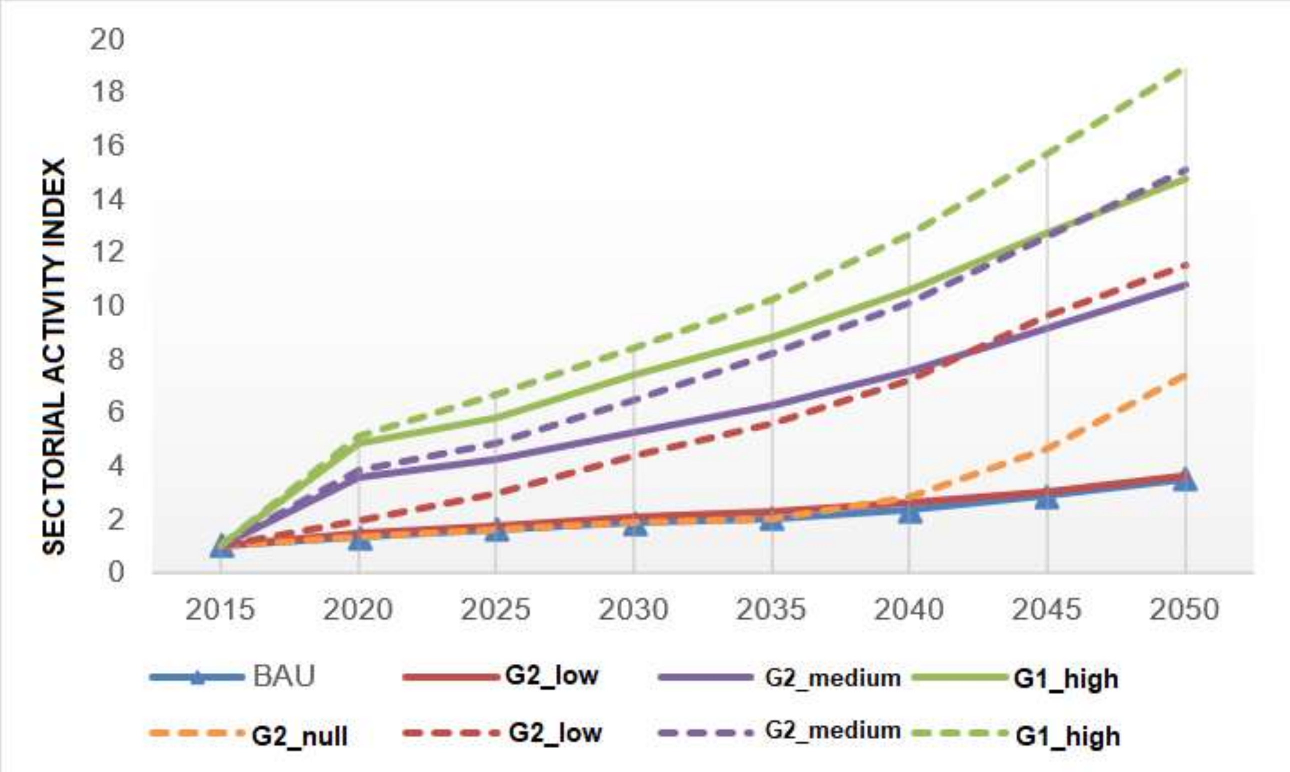

Figure 2 – Activity index for the forestry sector in the period from 2015 to 2050 for all simulated scenarios in this study (reference scenario, scenarios of group 1 and scenarios of group 2).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The new demand and the increase in the production of forest biomass as an energy source suggests a considerable impact on the activity index of the forest sector. In the model, to the extent that there is an increase in the degree of government subsidy and/or reduction in costs for commercialization of this new technology, there is an expansion in the activity of this sector.

Brazil has great potential to generate the use of biomass as an energy source, so a potential source of resources is not necessary for sustainability control systems (SOARES et al., 2006). Also counting with the information from this study, Brazil adds all the conditions to be able to get its energy power through processes that enhance this renewable resource (COUTO et al., 2004).

4.1.2. Agricultural Sector

The model used in this study presents the agricultural sector divided into two groups: the agricultural sector for crop production and the livestock sector. Therefore, the sectoral activity index was analyzed for each group individually.

The index of activity for the agricultural sector focused on crop plants presented a similar evolution in all scenarios analyzed. An increase of this sector was observed during the 35 years evaluated, with a growth of 147.8% of the sector in the reference scenario. For the simulations of group 1, the development of the sector follows the same pattern, with only a small negative variation, that is, decrease of the activity index in relation to the reference scenario for the year 2050 according to the different levels of subsidy, being the fall values, 0.6%, 2% and 2.1% for the low, medium and high investment scenarios, respectively. The same occurs in the simulations of the second group, also presenting negative deviation of 0.8%, 1.9%, 2% and 2.5% for the non-investment scenarios and low, medium and high investment scenarios, respectively, in relation to the scenario (Figure [ ]).

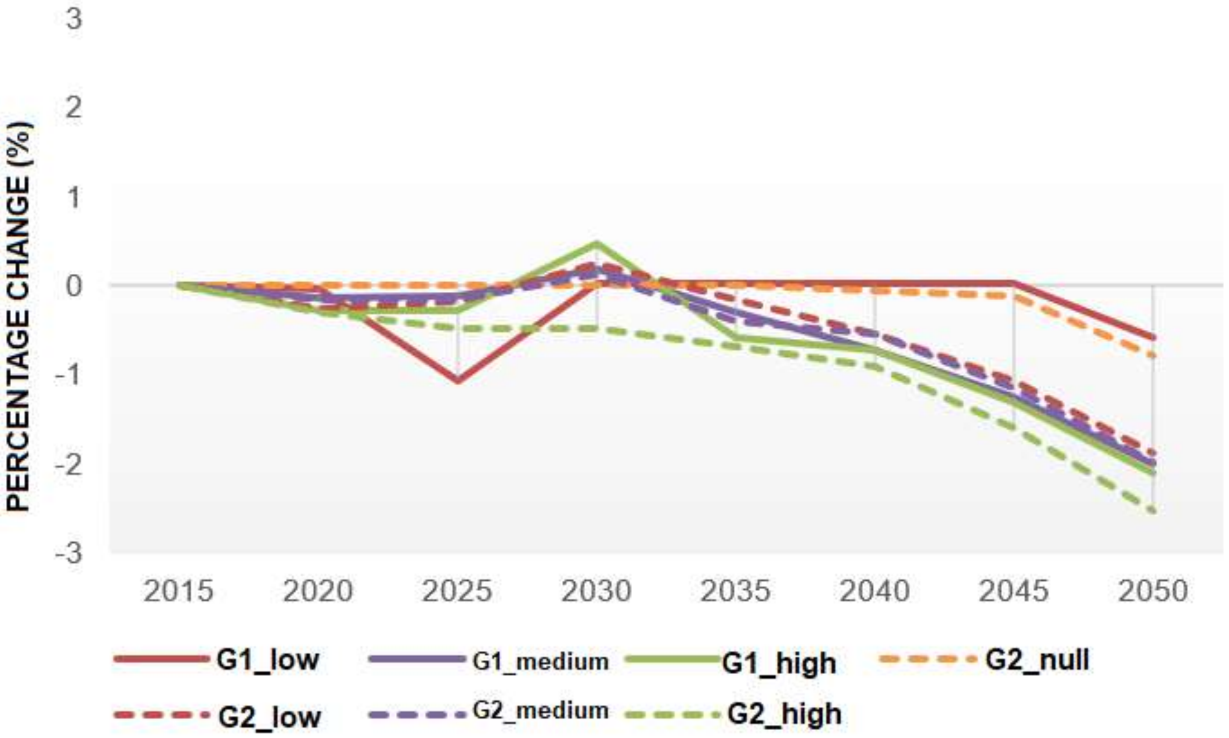

Figure 3 – Percentage change (%) of the activity index for the agricultural sector in the period from 2015 to 2050 in relation to the reference scenario for the scenarios of group 1 and scenarios of group 2.

Source: Own elaboration.

Note:

G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_ medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

A similar context was seen for the agricultural sector focused on livestock. The reference scenario presented a 106.8% evolution in the activity index of this sector. For the simulations of group 1, the development of the sector follows the same pattern, with only a small variation of decrease for the year 2050 according to the different levels of subsidy in relation to the reference scenario, with the rates of fall being 0.5% 1.5% and 1.5% for the scenarios G1_low, G1_medium and G1_high, respectively. The same occurs in the simulations of the second group, showing negative deviations of 0.6%, 1.4%, 1.3% and 1.7% for the non-investment scenarios and low, medium and high investment scenarios, respectively, in relation to BAU (Figure [ ]).

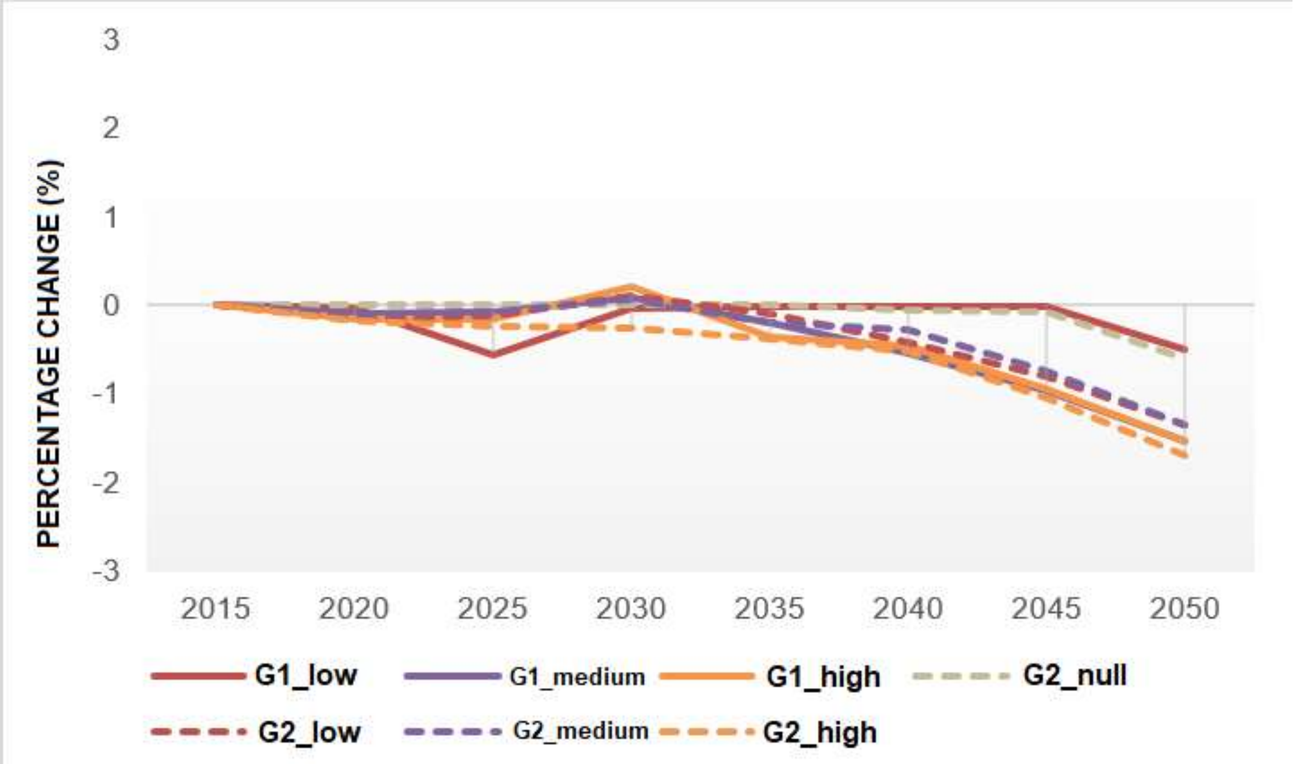

Figure 4 – Percentage change (%) of the activity index for the livestock sector in the period from 2015 to 2050 in relation to the reference scenario for the scenarios of group 1 and scenarios of group 2.

Source: Own elaboration.

Note:

G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

Although it is small, it is noticed that there is an increase in the subsidy degree for energy generation from biomass, there is no index of the agricultural sector. Comparing with the data obtained for the forest sector, where the values reach up to 441% growth, it can be said that the central part of the research is an impact factor on bioelectricity from forests with grid, and, therefore, a competition for land use among sectors is minimal or even irrelevant.

4.1.3. Chemical Sector

For the chemical sector, the model also suggests modest impacts in all scenarios analyzed. The reference scenario has an activity index growth of 250.6%, which is very similar for all simulations. The first scenario of group 1 (low investment grade) did not show any difference of production index in relation to the BAU scenario, while the medium and high investment scenarios showed a slight decrease of 0.1% and 0.4% respectively. The simulations belonging to the group with the learning curve (group 2) reacted as follows: in the scenarios G2_null and G2_low, an increase occurs in relation to the reference scenario of 0.1% in each one; in the G2_medium scenario there is a decrease in the activity index of 0.2% in relation to the reference scenario and finally, in the G2_ high there is also a decrease in the index of 0.6% (Figure [ ]).

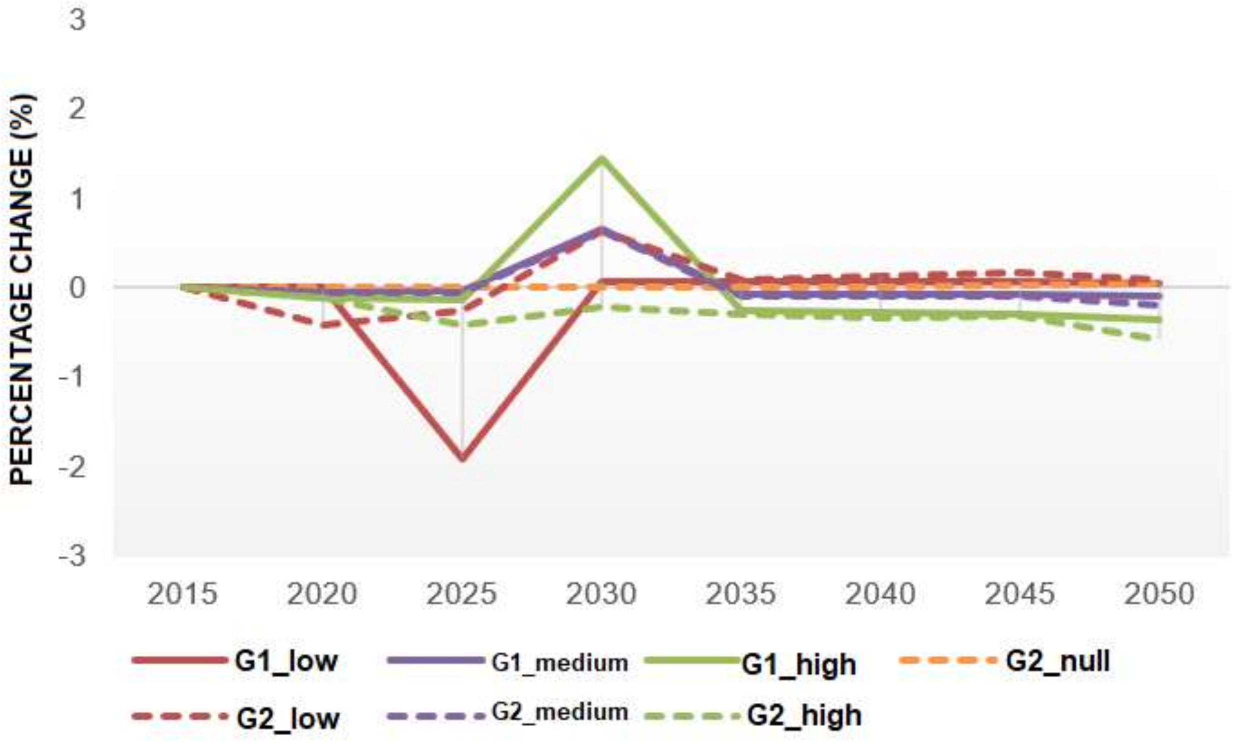

Figure 5 – Percentage change (%) of the activity index for the chemical sector in the period from 2015 to 2050 in relation to the reference scenario for the scenarios of group 1 and scenarios of group 2.
Source: Own elaboration.
Note:
G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

From the data analyzed for this sector, there are very low variations in the evolution of the activity index for the chemical sector in relation to the reference scenario, which does not involve biomass. Therefore, in this case, the increment of bioelectricity over the years does not represent competition for the forest raw material destined for paper and pulp, and, therefore, little affects this sector of the economy.

4.1.4. Steel Sector

The steel sector behaves in a manner analogous to the chemical sector, according to the model presented in the study. All scenarios had an advance over the course of these 35 years in the activity index. The reference scenario showed a growth of 185%, which is similar in all other simulations. For group 1, the investment scenario has a positive change of 0.1% in relation to the reference scenario, and the other two scenarios (G1_medium and G1_high) presented a fall in these indexes of 0.1% and 0.6%, respectively. The scenarios of group 2 reacted in a similar way to the chemical sector, with an increase in the activity index in relation to the reference scenario, a positive variation of 0.1% for the first two simulations (G2_null and G2_low); and then there is no index of 0.4% and 1% for the G2_medium and G2_high scenarios, respectively (Figure [ ]).

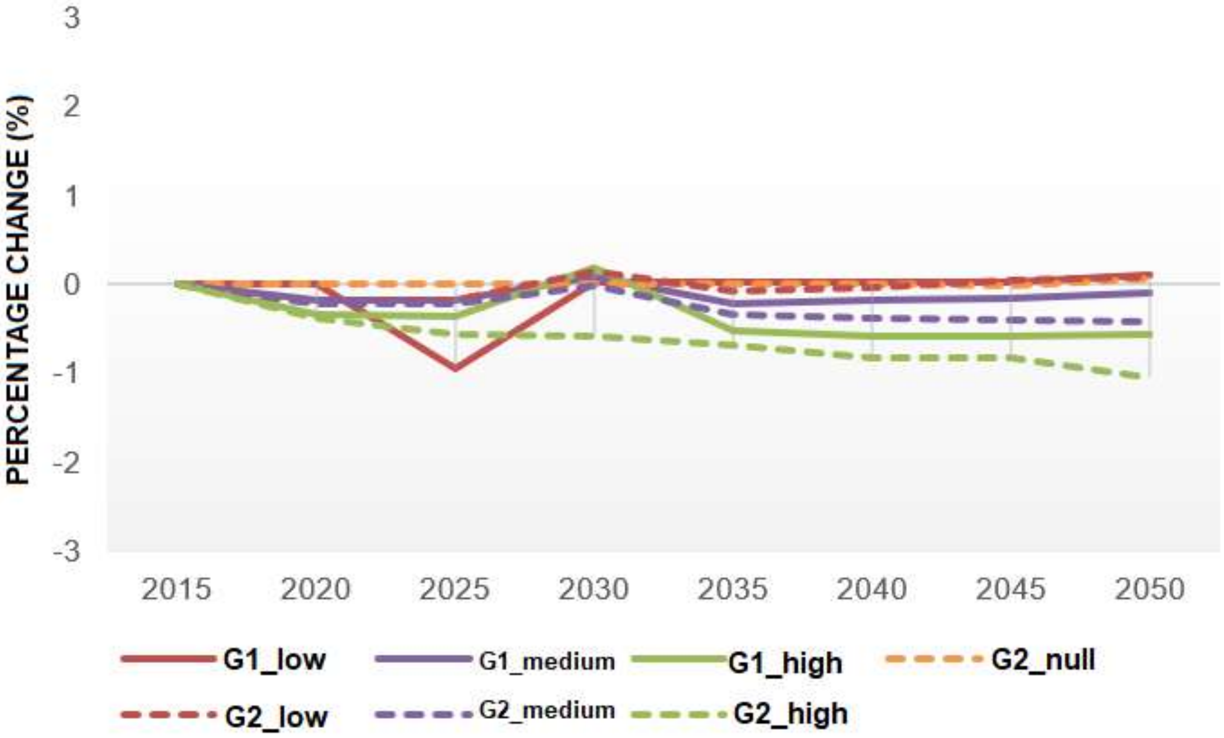

Figure 6 – Percentage change (%) of the activity index for the steel sector in the period from 2015 to 2050 in relation to the reference scenario for the scenarios of group 1 and scenarios of group 2.

Source: Own elaboration.

Note:

G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The same result of the chemical sector can be applied in the steel sector, where the presented data suffered very small variations in the development of the index of activity for this sector in relation to the reference scenario. Thus, the increase in bioelectricity over the years also does not affect this sector of the economy and does not represent a threat due to the demand for the same raw material. Considering the other results presented so far, it can be concluded that there is enough room for the growth of forest-based bioelectricity in the country through the expansion of planted forests, which is able to expand and continue to supply traditional forest-based activities. At the same time, this expansion in the production of planted forests does not compromise agricultural production, that is, it has a derisory effect in the competition for land use.

4.2. Share of the source in the energy supply

The share of sources in energy supply over the years was the second variable of interest in this study. This variable presented values for four different types of sources: forest biomass electricity, fossil-based electricity, sugarcane electricity, and electricity from water sources.

The first analysis was based on the percentage of participation of forest biomass in the national electricity supply. This environment does not have the reference scenario because BAU excludes the possibility of implementing the technology of electric energy generation through forest biomass.

It was observed that in all the analyzed simulations there was an increase in the percentage of participation of the forest biomass in the electric matrix. In the first group, these percentages reached, in 2050, values of participation in the grid of energy of 1.9% in scenario G1_low, 20.9% in G1_medium and 31,1% in G1_high. Considering the second group, these percentages reached even higher levels, being 11.3% for the G2_null scenario, 28.7% for the G2_low scenario, 39.1% for the G2_medium and 49.2% for the G2_high scenario (Figure [ ]).

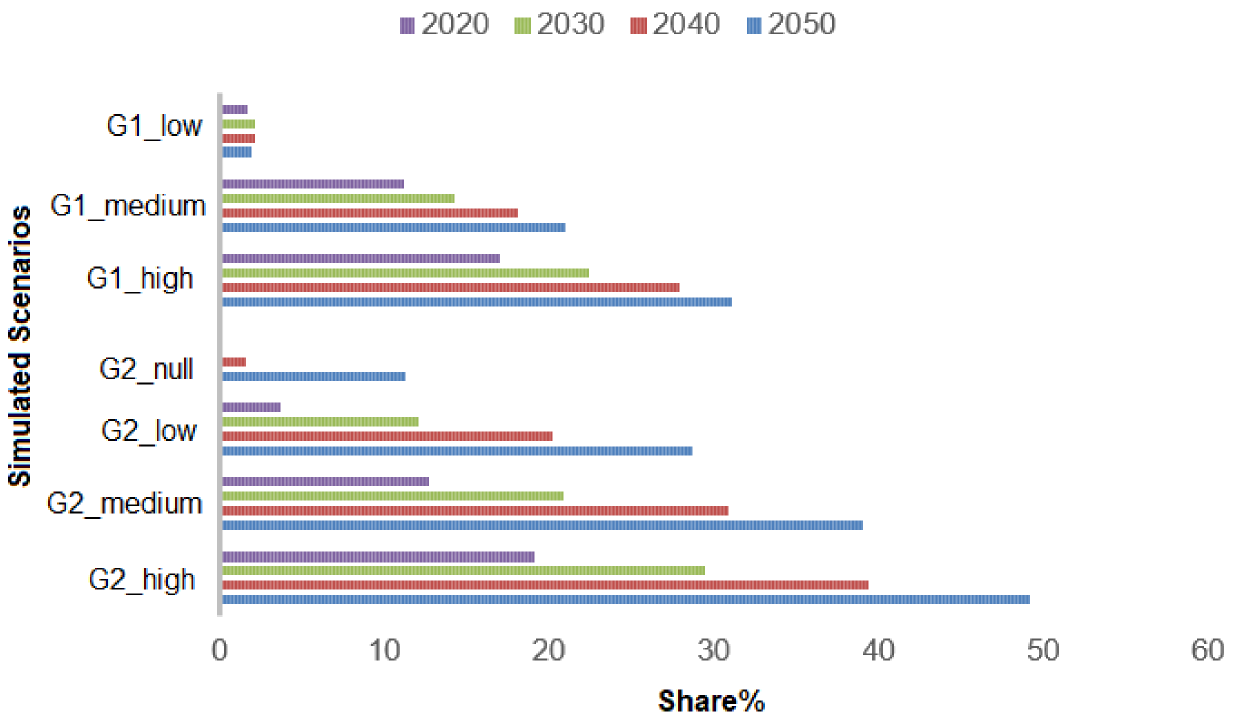

Figure 7 – Share (%) of forest biomass electricity in the generation of energy between 2020 and 2050 for the scenarios simulated in this study (scenarios of group 1 and scenarios of group 2).

Source: Own elaboration.

Note:

G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

It was noted that as there is an increase in the degree of government subsidies, there is also an increase in the percentage of participation of the technology of electric power generation from the forest biomass.

The second point explored referred to the percentage of participation of fossil origin in the supply of energy. It was observed that this source of energy undergoes different variations over the 35 years studied in the model in each scenario, mainly for the first time a fall, followed by an increase in the participation of the electric grid from 2015 to 2050. A significant point was observed that as the participation of forest biomass in the energy supply (different scenarios) is encouraged, the lower the growth of energy of fossil origin over the years and in the latter cases, a decrease in this participation was observed. For example, in scenarios where subsidies are null or low (G1_low, G2_null and G2_low), there was an increase in the share of this source during the study period (35 years), respectively, 70%, 61.8% and 7.5%. In the simulations with the highest levels of subsidies (G1_high and G2_high), the percentages of participation suffered a fall for the source analyzed, respectively, 6.9% and 90% over the 35 years analyzed.

However, the most relevant factor for the study are the comparisons made with the reference scenario, which corroborate the above information. The share of electricity of fossil origin in the reference scenario was projected at 24.9% in 2050. In other scenarios, the plots decrease while increasing the incentive degrees and reducing costs for forest biomass. For the scenarios of group 1 (G1_low, G1_medium and G1_high), 0.7%, 22.8% and 45.7%, respectively, were projected lower than the reference scenario. The simulations of the second group (G2_null, G2_low, G2_medium and G2_high) also presented fall values in relation to the reference scenario, being 4.1%, 37.2%, 67% and 94.2%, respectively (Figure [ ]). It is interesting to note that in the scenario of higher subsidy with learning curve (G2_high), the development of forest-based bioelectricity can completely replace fossil fuel electricity in the year 2045, suggesting that this technology has the potential to “clean” the Brazilian electrical matrix of fossil sources in a scenario of fighting climate change.

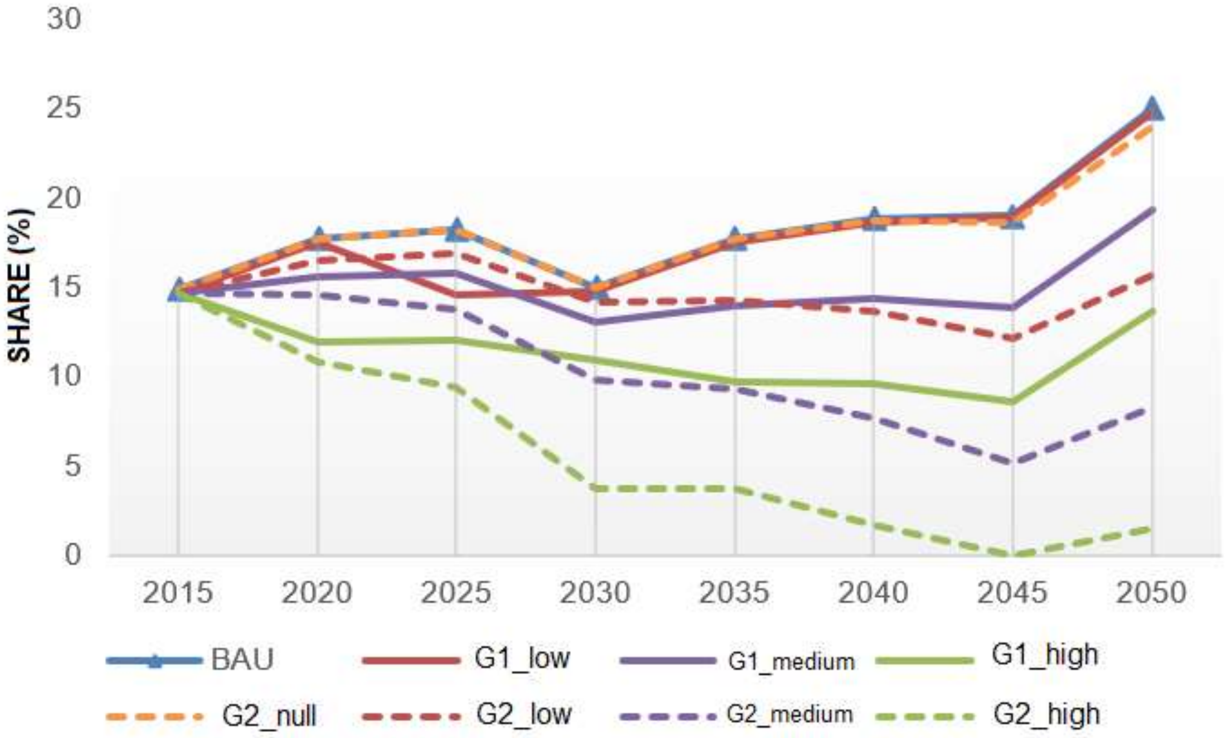

Figure 8 – Share (%) of fossil-source electricity in the generation of energy in the period from 2015 to 2050 for the scenarios simulated in this study (reference scenario, scenarios of group 1 and scenarios of group 2).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The third source evaluated referred to the electricity of the biomass of the sugarcane. Observing the results for this source, it was possible to measure the same regarding the source of fossil origin, that is, to the extent to which the participation of forest biomass in the energy supply (different scenarios) is encouraged, the smaller the growth of this source and, in the latter cases, there was a fall or even a non-participation in the electricity grid. The share of sugarcane biomass in the BAU scenario is 6.5% in 2050, an increase of 46.7% over the course of 35 years. The scenarios with the lowest investments (G1_low and G2_null) still showed an increase in participation, being, respectively, 46.9% and 33.6%. The other simulations showed a fall in the share of this source in the supply of energy, reaching null share in previous years to 2050, except for the G1_medium scenario in which there is a fall of 38.5% and participation of 2.7% in 2050.

In relation to the reference scenario, all simulations showed declining share in energy supply for 2050. The only scenarios that do not falld by 100%, this means, not indicated participation in the electricity grid, were the scenes with lower incentives (G1_low, G1_medium and G2_null), respectively, obtaining values of fall of 1.4%, 58.7% and 9% (Figure [ ]). The other simulations did not project participation for the source of biomass of sugarcane for the year in question. This result highlights the need to coordinate potential policies to encourage renewable energy, as the two most promising technologies for bioelectricity should become competitors in the absence of such coordination.

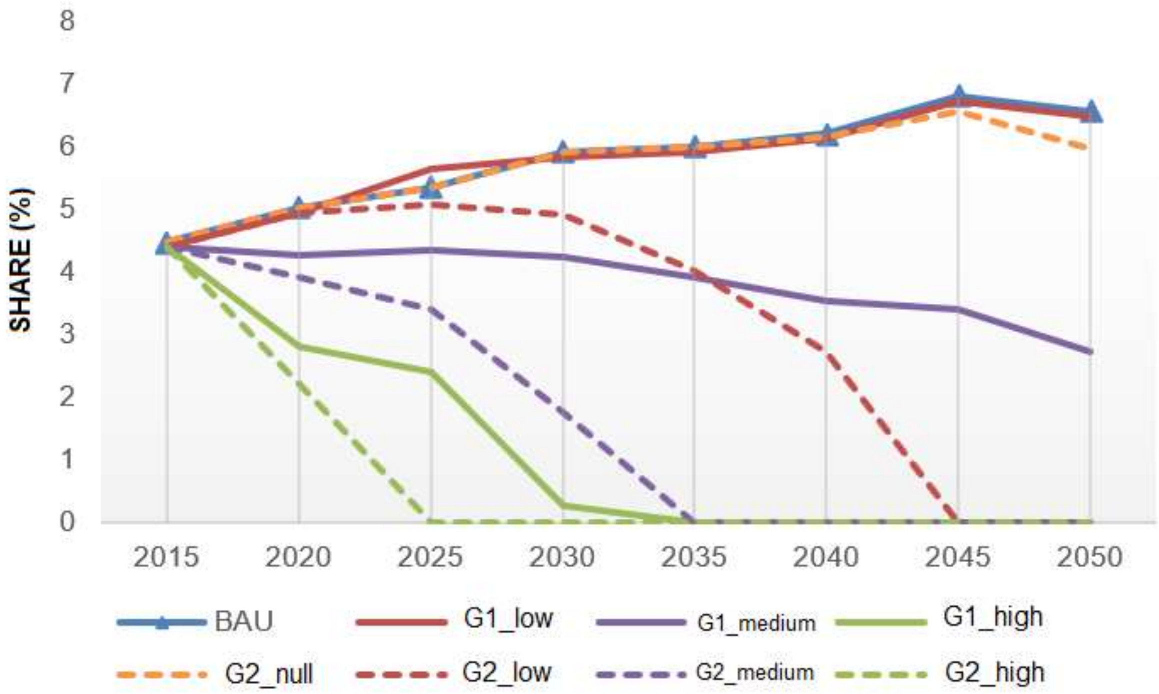

Figure 9 – Share (%) of sugarcane biomass electricity in the generation of energy in the period from 2015 to 2050 for the scenarios simulated in this study (reference scenario, scenarios of group 1 and scenarios of group 2).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The fourth source studied relates to electricity of water origin. The evolution curve for this source followed the same trend over the years analyzed, with a fall in the share of hydraulic electricity in the Brazilian energy grid. The reference scenario presented a fall of 18.2%, while the scenarios of the first group (G1_low, G1_medium and G1_high) had rates ranging from 18.1%, 19.9% and 22.4%, respectively. Scenarios of the second group (G2_null, G2_low, G2_medium and G2_high) reached rates of fall of 18.5%, 22%, 26.1% and 30.7%.

Comparing with the reference scenario, it was noticed that the variations of the participations of this source of resource were very small, mainly when related to the other sources already described in this research. The scenarios with lower levels of subsidy (G1_low, G2_null and G2_low) showed null or low fall, being 0%, 0.4% and 4.7%. However, other simulations (G1_medium, G1_high, and G2_medium, and G2_high) showed a production fall from the hydraulic source, respectively 2.2%, 5.2%, 9.7% and 15.4% (Figure [ ]). This result also suggests the need for coordination in stimulating different sources of renewable energy.

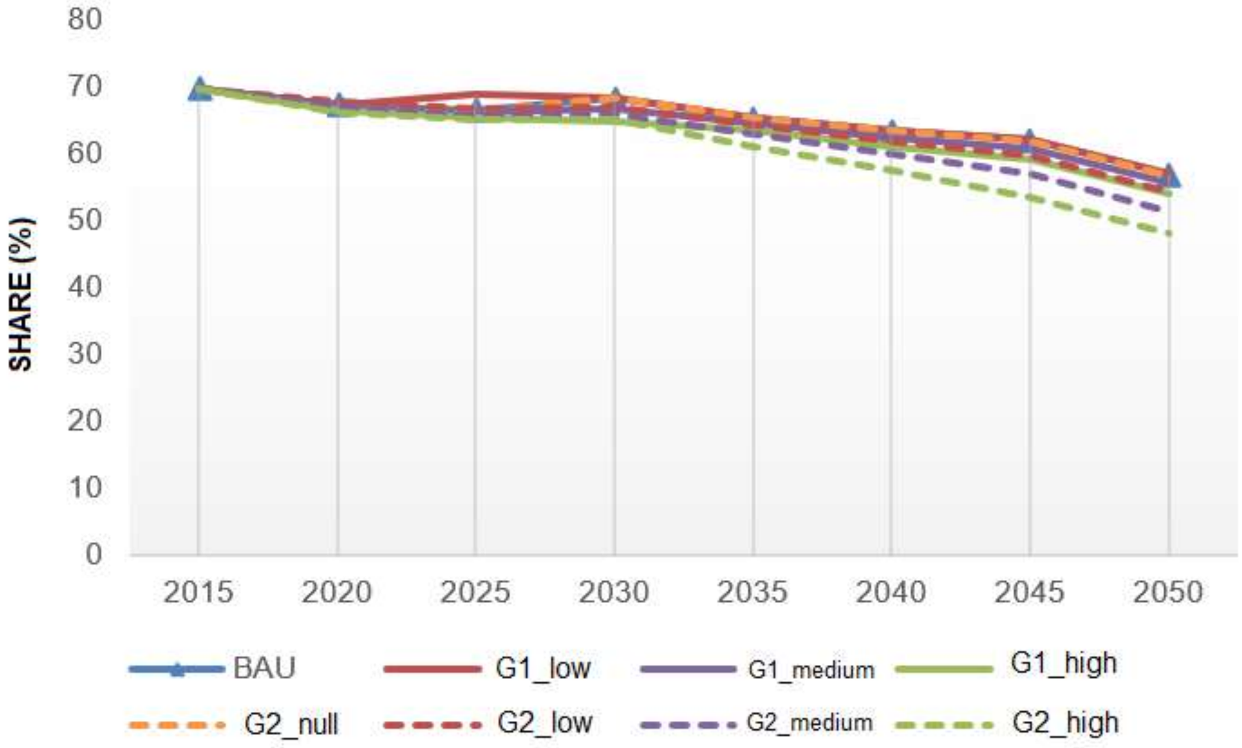

Figure 10 – Share (%) of hydric-source electricity in the generation of energy in the period from 2015 to 2050 for the scenarios simulated in this study (reference scenario, scenarios of group 1 and scenarios of group 2).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

4.3. Gross Domestic Product – GDP

Another variable of importance generated by the model is related to the gross domestic product (GDP). The general balance models allow, in addition to results on the studied products and different economic sectors, results on macroeconomic factors. In this way, it is important to analyze whether the different possible ways of using forest biomass for electricity generation can cause changes in the country's GDP.

From the results obtained, the model projects that the national GDP grows at an average rate of 2.85% per year during the period from 2015 to 2050 for the reference scenario, growing from US$ 1.8 trillion to approximately US$ 4.6 trillion. The same annual growth rate can be verified for the other scenarios evaluated, which only range from 2.83% to 2.85% of growth per year.

Analyzing group 1, the scenario with low investment had an annual GDP growth of 2.85% and presented a negative variation, that is, there was a fall in GDP value of 0.03% in the year 2050 in relation to reference scenario. The scenario with medium investment grew at a rate of 2.84% per year and compared to the reference scenario there was a slight fall, with a deviation of 0.2% in the year 2050. The same occurs for the scenario with high incentive, obtaining growth rates of 2.84% per year and a negative variation of 0.4% in 2050.

The simulations of group 2 also presented similar rates among themselves and with other scenarios, in addition to having very slight growth or fall rates in the year 2050 in relation to the reference scenario. The scenario with cost reduction but with null incentives presented a growth rate of 2.85% per year and no significant difference of fall or growth in the year 2050. The same growth rate is seen for the scenario with cost reduction and with a positive variation of 0.3% in relation to the reference scenario in 2050. The last two scenarios, both with a cost reduction coupled with medium and high investment, presented growth rates of 2.84% and 2%, 83%, respectively, and a slight fall in the value of national GDP, with a deviation of 0.1% and 0.4%, respectively (Figure [ ]).

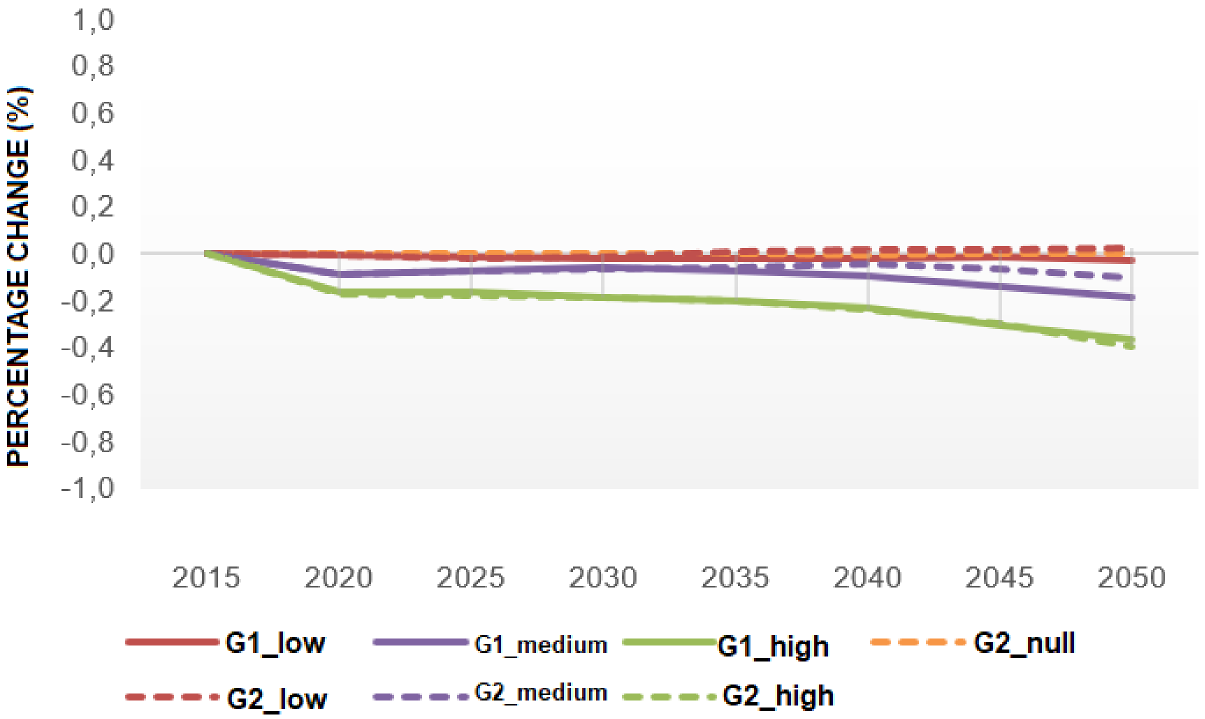

Figure 11 – Percentage change of gross domestic product – GDP (US$ billion) in the country for the period from 2015 to 2050 for all scenarios simulated in this study (scenarios of group 1 and scenarios of group 2).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

These results suggest that annual growth rates are not affected by the different scenarios evaluated, that is, the values obtained are not very significant to impact the value of the national GDP. This means that the incentives in the form of subsidies provided to the forest-based bioelectricity sector are not capable of distorting the allocation of resources in the economy to the point of causing undesirable changes in the country's economic growth trajectory.

A similar result was found in Maluf (2014), who studied the influence of the production of sugarcane biomass for the generation of electricity and liquid fuels (second generation ethanol) on the trajectory of national and international GDP, suggesting that annual rates of GDP growth are virtually unaffected by a scenario of strong bioenergy expansion of sugarcane.

4.4. Land Use

The last variable of interest analyzed in the study was land use. It was evaluated the fall or growth of areas destined to four major classes of use: forest production (planted forests, managed forests and regenerating secondary vegetation), plant crops, pastures (cattle raising) and natural forests.

Firstly, the evolution of the size of the area destined to the production of planted forests during the years 2015 to 2050 was analyzed. This variable also considers the values of growth of the secondary vegetation, not being possible the separation of these two uses in the model.

In this case, the first two scenarios behaved differently from the others. The reference scenario presented a 13% fall in the area destined to forest production and secondary vegetation, and the same fall rate can be observed for the first scenario of group 1 (G1_low). Considering that forest production is increasing in the reference scenario (see Figure 12), the reduction of this category of land use means conversion of areas of secondary vegetation to other uses and increased efficiency in forest management over time. The other scenarios presented opposite direction in the results, showing the same growth trend in the forest production area, to meet the expansion of biomass demand for electricity over the years. The growth rate for all remaining scenarios (G1_medium, G1_high, G2_low, G2_medium and G2_high) was 56% until 2050, except for the scenario of group 2 devoid of public incentives, which represented a growth in the forest area of 30%.

Comparing the simulations with the reference scenario for the year 2050, a growth of 126% was observed in the areas of forest production, except for two scenarios: G1_bass with a 26% increase and G2_null with a 49% increase in the year 2050 (Table 2). These data corroborate the fact that the presence of government subsidies contributes to the increase of the forest area destined to the production of forest biomass (Figure [ ]).

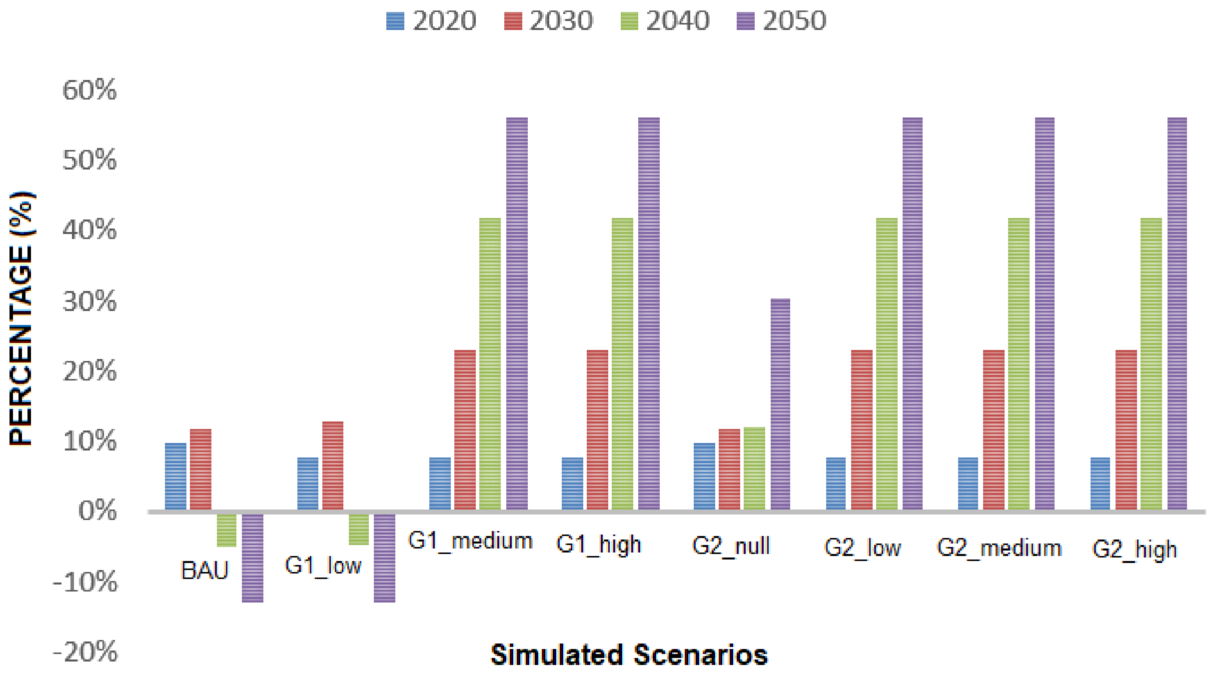

Figure 12 – Percentage of land use evolution for forest production in relation to the year 2015 for all the scenarios studied (baseline scenario, group 1 scenarios and group 2 scenarios)

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The second classification of land use was relative to the areas of crop production, where all scenarios were similar. In all simulations, there is an increase in the area required for plant crops, following the data presented for the activity index of the agricultural sector. The BAU scenario presented the highest growth rate (81%), followed by the first scenario in group 1, representing an increase of 78%. The other scenarios reproduced growth rates with values between 71% and 72%, except for the G2_null scenario with the rate of 77%.

Regarding the reference scenario, the other scenarios indicated a decrease in the size of the area of 5% in the year 2050, except for the scenarios G1_low and G2_null that presented a percentage of fall of 2% (Figure [ ]).

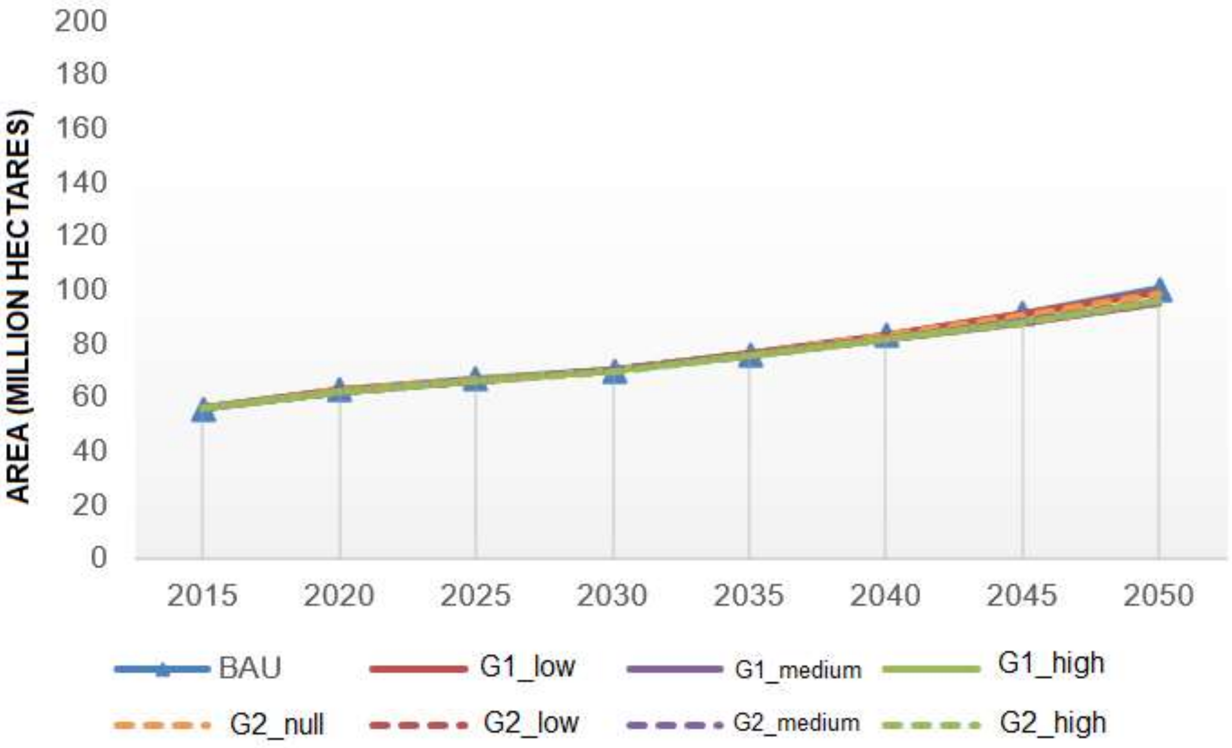

Figure 13 – Area (million hectares) for crop production in the country for the period 2015 to 2050 for all scenarios simulated in this study (baseline scenario, group 1 scenarios and group 2 scenarios).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The fact that the highest growth rates of the areas for crop production are located in the first two scenarios, which showed a fall in the area of forest production, in addition to having been detected a decrease in the size of the territory in all scenarios in relation to the reference scenario, show that there is a slight competition between the areas of vegetal crops and the one destined to the production of the forest biomass. However, as the current area of crops is much more expressive than that of planted forests, a 50% increase in forest areas is possible with only a 5% reduction in crop area expansion.

The third classification of land use presented by the model is related to the areas destined to the production of pastures (cattle raising). In all scenarios, there was a fall in these areas, differing only in degrees of values according to the level of subsidy attributed to forest biomass. For the reference scenario, there was a fall of 3% in the pasture area. Considering the simulations of the first group, G1_low, G1_medium and G1_high, the fall rates were, respectively, 7%, 14% and 12%. For the scenarios of the second group, G2_null, G2_low, G2_medium and G2_high, the rates obtained were 7%, 14%, 12% and 12%, respectively.

In relation to the BAU scenario, all other scenarios presented a certain degree of fall in their areas. The two scenarios with lower subsidy levels, G1_low and G2_null, showed a decrease of 4%, while the other scenarios generated a fall in the range of 9% to 11% in 2050 (Figure [ ]).

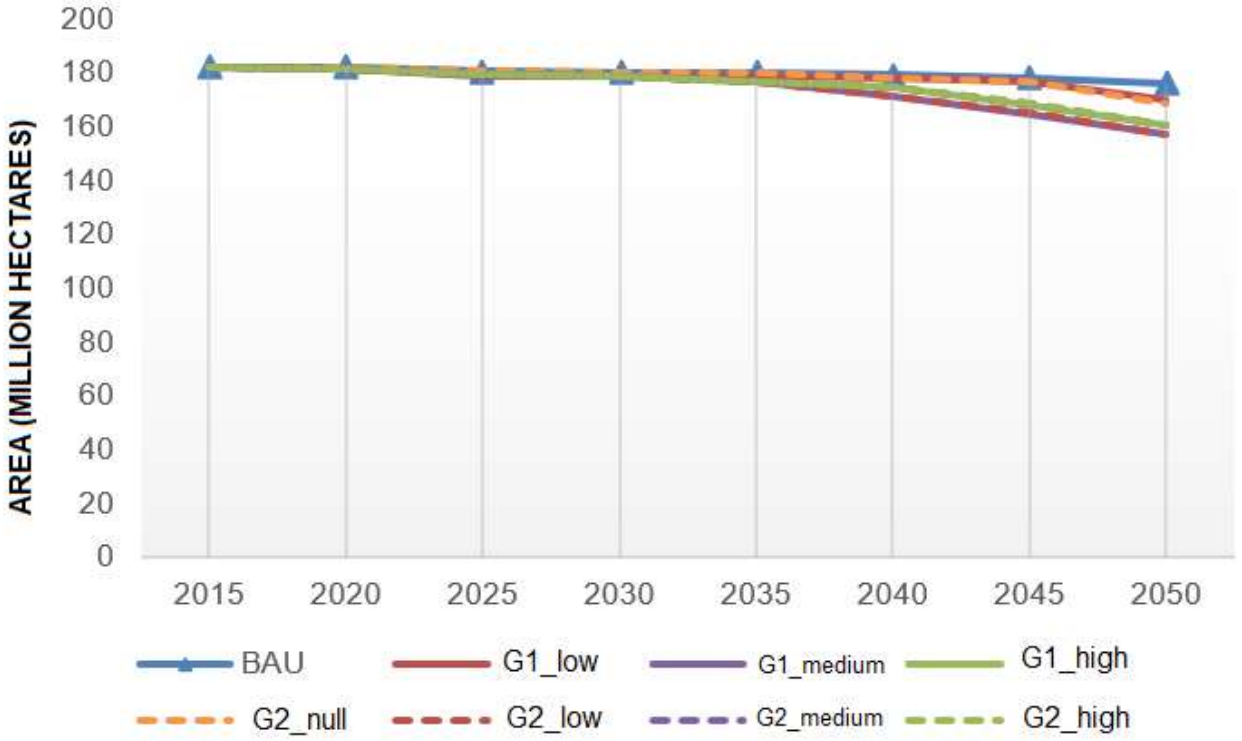

Figure 14 – Area (million hectares) for pasture production in the country for the period 2015 to 2050 for all scenarios simulated in this study (baseline scenario, group 1 scenarios and group 2 scenarios).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

The fall in pastures observed in all scenarios is a consequence of the intensification process and better utilization of the existing pasture areas, given the low average level of productivity of Brazilian livestock. The strong expansion of the forest biomass can intensify this process of increasing the productivity of the Brazilian pastures.

The fourth classification related to vegetation areas of natural forests in the country. Evaluating over the course of 35 years, similar behavior was observed for all scenarios. There was a fall in the area of 3% in all the scenarios analyzed between the years 2015 to 2050, as well as a decrease of 0.2% in the area of all the scenarios (G1_low, G1_medium, G1_high, G2_low, G2_medium, G2_high) when related to the reference scenario, except for the scenario of the second group without investment (G2_null), which had no change in relation to the BAU (Figure []).

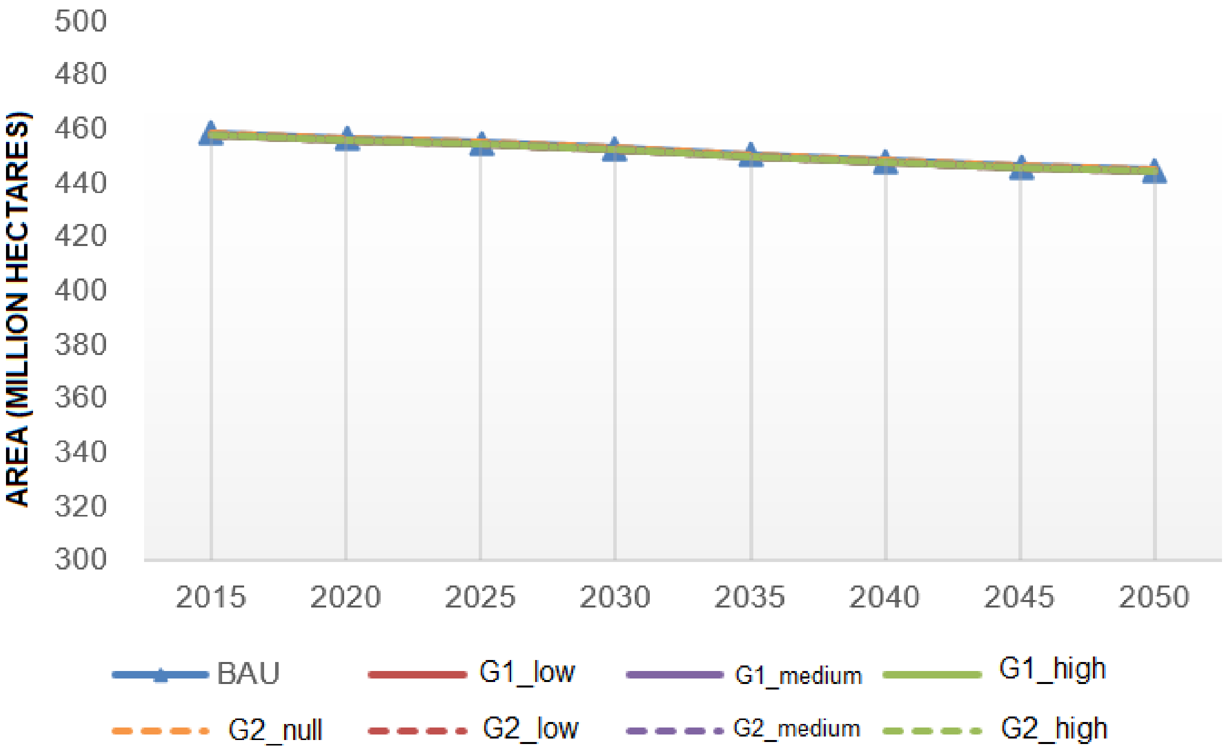

Figure 15 – Area (million hectares) for natural forests in the country for the period 2015 to 2050 for all scenarios simulated in this study (baseline scenario, group 1 scenarios and group 2 scenarios).

Source: Own elaboration.

Note:

BAU: baseline scenario; G1_low: low investment; G1_medium: intermediate investment; G1_high: high investment; G2_null: learning curve and without investment; G2_low: learning curve and low investment; G2_medium: learning curve and intermediate investment; G2_high: learning curve and high investment.

These values were very small compared to the growth rates of the forest production sector and, mainly, did not change as there were changes in the degrees of incentive for the introduction of biomass in the country. Therefore, it is not possible to affirm that the production of forest biomass has some degree of influence on the areas of natural vegetation.

Taking together the results of changes in areas and production, it can be inferred that there are possibilities of increasing efficiency in Brazilian agricultural production capable of accommodating a strong expansion of the forest biomass sector. Competition for land use for food production and bioenergy would not impact deforestation rates, nor would it jeopardize the country’s role in the production and export of agricultural products.

5. CONCLUSIONS

Expectations regarding the development and advancement of renewable energy sources are vast and Brazil meets the most diverse conditions for the establishment of this new reality. Forest biomass is a renewable source of great interest for the generation of electric energy in the country, but for a better use of this unexplored source it is necessary to have an injection of attractive investments in the production and commercialization of the same.

One of the first results of this research suggests that the activity index of the forest sector is closely related to the new demand and to the increase of the production of forest biomass for electric power generation. However, the expansion of this sector is dependent on government incentives and/or reduced costs for the production and commercialization of this new technology. In a scenario with no incentive for forest-based bioelectricity, the planted forest sector shows a growth of 111.5% in relation to the reference scenario until 2050, while in scenarios with incentives and cost reduction, the sector shows more expressive values of growth, such as an increase of 329.9% and 441%, respectively, in relation to the reference scenario. In addition, a strong penetration of bioelectricity from forest biomass into the energy matrix has almost no impact on other economic sectors more related to the use of wood, such as the chemical sector and the steel sector, nor its main competitor in the use of the land factor, the agricultural sector. Within these three sectors, agricultural production is the one that has suffered most influence over the years, contracting in 2.5% for crops and 1.7% for livestock in the most aggressive scenario of expansion of the forest sector.

Another important result is related to the participation of the different energy sources in the Brazilian grid. The evolution of the participation of forest biomass electricity in scenarios with little incentive is very small, ranging from 1.9% to 11.3% of participation in the year 2050, differently from the simulations with a high degree of incentive, in which the participation percentage can reach higher values, such as 49.2% share in its more aggressive scenario. This fact corroborates the need for improvements and investments to help the growth of this sector. In addition, it is observed that the most affected sources of electricity would be those of fossil origin and biomass of sugarcane, that is, the production of bioelectricity from the forest biomass tends to reduce or even to replace the participation of these two segments in the national grid. This shows that, while forest bioelectricity can contribute to reduce greenhouse gas emissions, it can also compete with other renewable sources, requiring coordination efforts in policies to encourage these sources to avoid such competition.

The incentive to produce forest biomass as a source of energy does not have a negative impact on the Brazilian GDP. Thus, there are no relevant distortions on national production to stimulate the expansion of this renewable source.

Still on the results, land use was also evaluated, and it can be said that the expansion of forest biomass causes slight competition for land use with crop and pasture, and does not change deforestation rates. There is room for productivity gains in agriculture and livestock in the face of scenarios of strong expansion of the forestry sector, since the impacts on land use are more significant than the impacts on agricultural production.

In addition to be a renewable resource, forest biomass presents several advantages such as low acquisition cost, less corrosion to the equipment, less aggressive ash, its handling and use do not add CO_2 to the atmosphere. In addition, its use for energy purposes can assist in the sustainable development of underdeveloped regions and rural areas. However, it is essential that the enablers of the energy sector together with the government identify the importance of this bioenergy as a vehicle for national sustainable development so that the capacity of this renewable resource is appropriately enjoyed.

In this way, it is essential to promote research, which is scarce in the country, bringing opportunities to future research on the use of forest biomass, improvements and impacts. Future works may also analyze the regional issue of biomass production for electric power generation, one of the limitations of the presented model. In addition, government actions are indispensable, which should encourage and assist in the growth and development of this new source of sustainable energy.

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