CC&T

ISSNe 0104-1096

Cadernos de Ciência & Tecnologia

www.embrapa.br/cct

Eucalyptus sp. reforestation as an option for thermal energy independence for grain drying with biomass in Brazil

João Victor Pereira Oliveira[1]
Larissa Carolina Corraide da Silva[2]
Delly Oliveira Filho[3]

ABSTRACT

The current worldwide energy scenario has concerned producers due to significant variations in prices in the energy source market. Energy price and availability play a significant role in the economic planning of a production process because it is essential for agricultural processes to prevent product losses during drying and storage. This paper presents an analysis of the area required and the economic viability of Eucalyptus reforestation and crop residues to provide energy self-sufficiency for the drying of agricultural products. In the cases analyzed in this present research, this practice was economically viable in up to 14 out of 15 situations. The minimum area required for reforestation ranged from 0.61% to 3.15% of the cultivated area for the products considered in this research. The scenario of unstable prices in Brazil after the Covid 19 pandemics and the Russia-Ukraine war drastically impact the results.

Index terms: agricultural residue, energy self-sufficiency, land use, woodchips.

Reflorestamento de *Eucalyptus* sp. como opção para alcançar independência de energia térmica na secagem de grãos no Brasil com biomassa

RESUMO

O atual cenário energético mundial tem preocupado os produtores agrícolas, devido às variações significativas de preços no mercado de fontes de energia. O preço e a disponibilidade de energia desempenham um papel significativo no planejamento econômico de um processo de produção, pois evitar perdas de produtos durante a secagem e armazenamento é essencial para os processos agrícolas. Este trabalho apresenta uma análise da área de cultivo necessária e da viabilidade econômica do reflorestamento de eucalipto e uso de restos culturais para prover a autossuficiência energética na secagem de produtos agrícolas. Nos casos analisados na presente pesquisa, essa prática foi economicamente viável em até 14 das 15 situações. A área mínima necessária para reflorestamento variou de 0,61% a 3,15% da área cultivada para os produtos considerados nesta pesquisa. O cenário de preços instáveis no Brasil após a pandemia de Covid 19 e a guerra Rússia-Ucrânia impactam drasticamente nos resultados.

Termos para indexação: autossuficiência energética, cavaco, resíduo agrícola, uso da terra.

Ideias centrais

- A adoção de reflorestamento com eucalipto contribui para se estabelecer um processo agrícola sustentável.
- Menos de 5% da área da lavoura, quando convertida em reflorestamento, pode fornecer energia térmica para secagem dos grãos produzidos.
- A sustentabilidade energética do processo de secagem de grãos é viável.
- A utilização de cavacos e resíduos da lavoura contribui para viabilizar a secagem dos grãos.
- A pandemia de Covid 19 e a guerra Rússia-Ucrânia impactam drasticamente na viabilidade de secagem de grãos no Brasil usando reflorestamento.

Recebido em
07/03/2023

Aprovado em
19/04/2023

Publicado em
18/07/2023

---

[1] Control and automation engineer, doctor in Agricultural Engineering, professor at Universidade Federal de Viçosa, Viçosa, MG, Brazil. E-mail: oliveira.jvp@ufv.br.

[2] Control and automation engineer, master in Agricultural Engineering, student at Penn State University, Pennsylvania, USA. E-mail: lkc5585@psu.edu.

[3] Electrical engineer, doctor in Electrical Engineering, professor at Universidade Federal de Viçosa, Viçosa, MG, Brazil. E-mail: delly@ufv.br.

DOI: 10.35977/0104-1096.cct2023.v40.27242

INTRODUCTION

Before an agricultural product reaches the consumer's table, it passes through several processing and storage stages. In general, products are not sold right after harvest, which requires preservation procedures. The drying of agricultural products is a primary preservation technique where the water content is reduced to prevent loss of quality due to different storage factors, such as microorganisms or insect infestation (Onwude et al., 2016).

Thermal energy input is necessary for an agricultural product to achieve the water content required for preservation, provided by several methods. However, it is necessary a comprehensive study on the energy sources which can be used for drying, since issues related to environmental impact reduction play a significant role in decision-making (Udomkun et al., 2020).

The use of renewable energy sources has increased in the world market, for both consumption and production. According to Timmons & Mejía (2010) and Verma et al. (2017), many countries seek to develop renewable energy sources, with an expressive amount from biomass, which is a renewable energy source composed of natural materials, such as forestry waste, agricultural crop residues, animal and plant remains, as well as all biodegradable material from industries and cities. Biomass significantly differs from fossil fuels, since instead of being concentrated near mines or wells, it is widely dispersed in the environment (Toklu, 2017).

The use of renewable energy sources, mainly from biomass, can potentially affect national and global ecosystems and the services provided with their use (Burgess et al., 2012). From a global perspective, renewable energy sources such as biomass have played an increasingly significant role in political decisions. According to Dercan et al. (2012), the public and politicians consider energy and bioenergy as fundamental issues, due to the uncertainty related to fossil fuel prices and a growing concern about nuclear energy use. The use of biomass as an energy source is considered because of its cost, availability, significant potential, renewability, and environmental benefits (Moya et al., 2019). In the 1980s, most developing countries' populations used renewable sources, generally biomass, as the primary energy source (Silva et al., 2018). Despite not being one of the pioneering countries in biomass use, Brazil has great significance to the biomass market since it has enormous plantation crops and, consequently, a great source of waste and residue feedstocks. Additionally, Brazil's large territory available to produce crops could be used without risk of deforestation for plantations (Welfle, 2017). In addition, water availability and Brazil's favorable latitude, at which tree growth is faster in its tropical climate, increase the Brazilian biomass potential (Kaida et al., 2009). By the end of the 1970s, diesel was the primary fuel used for drying processes in Brazil due to its low price and ease of use (Reinato et al., 2002). In January 1980, the National Petroleum Council banned the use of any petroleum derivative as fuel for drying agricultural products (Afonso Júnior et al., 2006). Thus, oil burners were replaced by firewood furnaces. Since then, biomass from purchased firewood is the most widely used energy source for drying used in Brazil, while in several parts of the world, oil and natural gas are the primary energy sources. Therefore, biomass is an essential alternative for thermal energy supply for drying agricultural products in Brazil.

Transportation from the collection site to the processing area is an important factor in biomass use (Bhutto et al., 2016). According to Golecha & Gan (2016), this is the most expensive stage in the use of biomass and does not differ from the use of purchased firewood in Brazil. Besides its price, there are other problems with firewood, for example, availability and delayed delivery, which significantly affect the production processes that depend on this fuel, such as the drying of agricultural products. Therefore, it is necessary to consider the energy costs and availability in the drying of agricultural products, according to the constant increase in productivity.

Some studies in the literature investigate biomass as an energy source and the costs related to its handling. For instance, Moya et al. (2019) reviewed the potential use of biofuel from short-rotation wood crops in Latin America. According to Williams et al. (2017), wood processing into chips or pellets increases, by 38%, burn efficiency in a knife mill. A current study has also been carried out focused on the advantages of using biomass from crop residues and its contribution to biomass production in China (Chen, 2016). Additionally, according to Singh et al. (2010), biomass is an alternative for energy independence in a productive sector, and it is essential to have it close to the process.

This present research aims to improve knowledge about biomass use on farms and its advantages/disadvantages. The amount of Eucalyptus forest that must be planted in an agricultural area to achieve thermal energy self-sufficiency was estimated. The economic feasibility of wood production in association with crop residues aimed at energy self-sufficiency for the thermal drying processes of agricultural products was analyzed. Firewood, woodchips, and crop residue were studied as energy source alternatives, considering their advantages and drawbacks regarding self-production or purchasing. Possible price variations were also addressed.

METHODOLOGY

The following biomass fuel cases were studied in this present research:

- **Case 1:** firewood as logs;
- **Case 2:** firewood as woodchips from logs, branches, or roots; and
- **Case 3:** agricultural biomass residue combined with woodchips.

Estimate the portion of the crop area for reforestation

This study considered five agricultural products and their Brazilian production, according to Brazilian Institute of Geography and Statistics - IBGE (2021), for calculation: coffee, corn, rice, beans, and soybean. This present research also followed the recommendation made by EPE (Tolmasquim & Guerreiro, 2014) regarding the portion of agricultural residue that should remain in the plantation area to maintain the soil quality: corn residue: 60%; rice residue: 60%; bean residue: 60%; and soybean residue: 70%. The total heat required for drying these products was considered to be 2,930.20 $kJ.kg^{-1}$ for products with water content between 15% and 30% wet basis and 2,720.20 $kJ.kg^{-1}$ for products with water content between 30% and 60% wet basis (Hu et al., 2018). Also, the average efficiency of agricultural drying equipment using wood as fuel was approximately 40% (Kaplan & Celik, 2018).

The firewood used for drying agricultural products was *Species* Eucalyptus sp., with an inferior calorific power of 13,813.80 $kJ.kg^{-1}$; in logs, the specific mass of the wood was 390 $kg.(m^3)^{-1}$ and 15% wet basis water content when dried. The energy required to dry the product is calculated based on the initial and final values of the product water content, which allows estimating the amount of biomass required, either firewood or agricultural residue. Table 1 shows these values.

Table 1. Energy and firewood required for drying of the products considered

Agricultural product	Water content at harvest (% wet basis)	Water content after drying (% wet basis)	Energy for drying (kJ / ton)	Firewood for drying (m3 / ton)
Coffee	45	11	4.204,980	0.88
Corn	25	13	1.172,070	0.25
Rice	20	13	640,980	0.13
Beans	25	13	1.172,070	0.25
Soybean	20	11	824,090	0.17

Economic analysis

This analysis was carried out considering a crop of 100 ha. The total area for reforestation was divided into seven equal portions, each with the capacity to provide the biomass energy for drying for one year. The first cut of Eucalyptus was assumed to be in the seventh year of the tree plantation. The total planning period was assumed to be 21 years, according to the reforestation life cycle. Thus, each cutting cycle was assumed to last seven years.

The economic analysis considered that the producer must buy wood in the first six years after reforestation, preceding the first cut. The estimated firewood production in the first, second, and third cuts was 15.60, 13.26, and 10.92 dry ton/ha, respectively (Afonso Júnior et al., 2006). Also, the considered average price of firewood in Brazil ranges from US\$19.00 to US\$ 25.00 per m^3 (Anuário…, 2022). Three fixed values were used in the presentation of the results: US\$ 19.00, US\$ 22.00, and US\$ 25.00.

The considered spending on firewood refers to inputs, consumables, equipment, and labor related to the implementation, maintenance, and operation of a Eucalyptus forest for 21 years. According to The costs of eucalyptus for reforestation is US\$570.00 (ha year)$^{-1}$, considering: seedlings and labor; weed, ant, fertilizer, firebreak control; and maintenance, including firebreak cleaning (Avila & Bester, 2017; Chichorro et al., 2017).

Land-related costs were calculated according to the price per hectare, and the return rate for farming was considered since the fertile land was used for farming. The average value of fertile soil ranges from US\$1,000.00 to US\$3,000.00 per hectare (Anuário…, 2022). For the analysis, this range was studied in five fixed values (US\$) – 1,000.00, 1,500.00, 2,000.00, 2,500.00, and 3,000.00). The interest rate was 8.75% (Schwantes & Araújo, 2021), which is used by the federal government to finance Brazilian agriculture major producers, considering the last stable interest rate in Brazil before the COVID-19 pandemic and the Russia-Ukraine war.

During these analyses, biomass was optimized by using small branches and roots as complementary biomass fuels in addition to firewood. Then, approximately 24% extra biomass could be recovered, and it was assumed to be used as woodchips, according to Manzone (2017). The data from a manual or crane-fed forest woodchopper was considered to optimize the firewood use by using wood chips. A diesel 360 hp engine powered the woodchopper. Diesel consumption and woodchip production were assumed to be 18 L h^{-1} and 40 m^3 h^{-1}, respectively. An equipment rental of US\$ 120.00 h^{-1} and eight-hour operation daily (MFRURAL, 2022) were considered.

The average value of reforestation and the agricultural residue generation were considered for the calculations according to product yield and their respective calorific power (Table 2). However, the agricultural residue from coffee was not calculated because the residue biomass from this product, that is, the coffee tree, requires a process and time interval different from those of the other cultures. In a coffee plantation, the coffee trees are trimmed at least every ten years, and their trunks and branches could be used as a biomass source of energy (Duarte et al., 2016). Coffee husk, another residue from coffee production, was not considered either because it has a significant value as a fertilizer source (Pandey et al., 2000).

Table 2. Agricultural residue generation according to product yield and respective calorific power

Agricultural products	Agricultural residue per crop production (ton_{ar}/ton_{cp})	Biomass inferior calorific power (kJ/kg)
Corn	1.68	17,700
Rice	1.44	16,000
Beans	1.16	14,000
Soybean	1.21	14,600

Source: Nascimento & Biaggioni (2010).

The net present value (NPV) – a method that calculates the net present value of all economic impacts that a project will accrue throughout its lifespan – was used in this economic analysis to indicate the relation between the costs of reforestation and the savings generated by not buying fuel for thermal energy generation. Thus, it shows that a project is considered economically viable when NPV is positive. In addition, annual revenue was represented by fuel cost savings. Thus, in the first six years – time before the first cut, when the producer needs to buy firewood –, the cash flow was negative. The NPV is defined according to the equation 1, as follows:

$$NPV = -I + \sum_{t=1}^{n} \left[\frac{C_{f_t}}{(1+k)^t}\right] + \frac{Q}{(1+k)^n} \qquad (1),$$

where: Cft is the cash flow in the capitalization period; I is the initial investment; k is the interest rate considered; Q is the residual value of the project (not applicable for this work); and n is number of capitalization periods considered in the analysis.

A sensitivity analysis (3%) was performed to assess the influence of land and firewood prices, determining which of these main variables were more significant in the economic analysis.

Considering Brazil’s vast territorial extension, a study was carried out to analyze the economic viability changes due to possible variations in land and firewood prices, separately, respecting the values presented in the literature. For this study, prices with variations of up to -15% (in relation to minimum prices) and +15% (in relation to maximum prices) were considered, and the economic feasibility was calculated for every variation of 5%.

The real-dollar quotation of R$ 5.19 per US dollar, from November 2022, was considered in this research (ACI, 2022).

A brief comment on recent events in Brazil, and the situation facing the post pandemic scenario and Russia-Ukraine war

In recent years, the world has been facing a crisis, of which one of the effects is the instability of prices in the market: the COVID-19 pandemic. Some authors suggest that this event altered the dynamics of commodity prices involving natural resources, as discussed by Guo et al. (2022). In Brazil, another aggravating factor for price instability was the war between Russia and Ukraine, since Brazil imports fertilizers from Russia. The imminence of scarcity influences the price of inputs, which directly affects the maintenance costs of a eucalyptus reforestation. Currently, Russia still sends fertilizers to Brazil, but the question of availability is constant (Duarte, 2022; Rodrigues, 2022). Recent studies indicate that the price for maintaining eucalyptus reforestation ranges from approximately US$1,200.00 to US$1,800.00 (Desiderio, 2021). This value would make any situation presented in this work economically unfeasible.

Another important factor to consider in the analysis of results is that Brazil has just ended elections for president, senators, deputies and governors (October and November 2022). At these times, it is common to see a variation of the dollar exchange rate and, consequently, temporary variations in the prices of products and services.

However, the literature suggests that immediate price variations tend to stabilize, as stated in Guo et al. (2022). In addition, it can be observed that, in 2022, the interest rate was close to the pre-pandemic values, as well as the price of firewood (Mazui, 2015; Desiderio, 2021; Moreira et al., 2021). This may be an indication of the normalization of prices in this sector. Therefore, it is important to adopt values in stable periods to indicate the economic viability or unfeasibility of what has been presented here.

RESULTS AND DISCUSSION

Estimated portion of the crop for reforestation

The required area of reforestation with *Eucalyptus* sp. for the drying of the respective agricultural products is presented for the studied cases, considering reforestation and planted area ratio (Table 3). In case 1, the reforestation area necessary for drying agricultural products was smaller than 5% of the crop area. Reforestation required a considerably smaller share of the crop area in case 2, due to the small branches and roots used as complementary biomass fuels in addition to firewood, in comparison with the case 1. Smaller proportions of land required for reforestation please growers who want to maximize the planting area. Therefore, the processing of wood into chips attracts their interest. These values reinforce the need of an economic analysis of reforestation in crops for energy self-sufficiency for drying since the required areas do not represent a significantly negative impact on agricultural production, considering the advantages they will provide. Case 3 required, on average, 28% less reforestation area than case 1; the average decrease of reforestation area required, in comparison with case 2 was approximately 3%. The use of agricultural waste is more advantageous together with woodchips since, by using woodchips, there is a considerable decrease in the area required for reforestation.

Table 3. Area required for reforestation with *Eucalyptus sp*. for the drying of agricultural products considered

Agricultural product	Reforestation and planted area ratio (%)		
	Case 1	Case 2	Case 3
Coffee	3.65	2.77	Not applicable
Corn	4.26	3.24	3.15
Rice	2.41	1.83	1.76
Beans	0.80	0.62	0.61
Soybean	1.68	1.26	1.22

Due to the increasing evolution of techniques and planting machinery, which demands more energy for drying, it will be possible to produce more agricultural products per hectare. Then, a larger area for reforestation is expected to be required over the years. According to Acompanhamento… (2016), there was a productivity increase of 52.34%, 91.58%, 71.55%, 50.41%, and 17.77% for coffee, corn, rice, beans, and soybean, respectively, from 2001 to 2018, when corn and rice were the two most affected cultivations by these changes. These values directly affect the calculation of the area required for reforestation since a reforestation profile for 2001 (case 1, firewood as logs), would be different from the current one, with a required area of 2.39%, 2.22%, 1.40%, 0.52%, and 1.42% for coffee, corn, rice, beans, and soybean, respectively. This would change the dynamics of results. For instance, corn needs a smaller area than coffee, and rice needs about the same soybean area.

It can also be observed that the water content difference in the product before and after drying significantly affects the definition of the area required for reforestation, as can be seen in the coffee results, in comparison with the other products. Even with a small yield, 1.31 tonne ha^{-1}, coffee requires 3.65% of plantation area for reforestation. Conversely, corn and rice have a close yield, 5.48 tonne ha^{-1} and 5.66 tonne ha^{-1}, respectively, with reforestation percentages of 4.26% for corn and 2.41% for rice.

Economic analysis of the studied cases

The economic analysis shows that, in case 1, the study results indicate that a project is economically feasible for any land valued at US$ 1,000.00 ha^{-1} (Table 4). Firewood cost at US$ 22.00 m^{-3} and US$ 25.00 m^{-3} turns the project viable on land with the price of US$ 1,500.00 ha^{-1}. However, for land valued at US\$ 2,000.00 ha^{-1} and US\$ 2,500.00 ha^{-1}, reforestation is only economically feasible if the firewood price is US\$ 25.00 m^{-3}. There is no economic viability for land at US\$ 3,000.00 ha^{-1}. It should be highlighted that the project was feasible in 7 out of the 15 simulations studied, which suggests that it is possible to implement reforestation in several situations, without the need to process wood in woodchips or the use of agricultural residue. Therefore, these results are essential for producers who do not have access to the woodchopper or intend to leave all the agricultural waste on land for soil fertilization purposes.

In case 2, the economic viability was achieved for any situation studied with a land price of US\$ 2,000.00 ha^{-1} or less. In this case, the project is economically feasible for any land price when the firewood price is US\$ 25.00 m^{-3}. The unfeasible cases occurred for land price at US\$2,500.00 ha^{-1} with firewood cost of US\$19.00 m^{-3}, and for land price at US\$ 3,000.00 ha^{-1} with firewood costs of US\$ 19.00 m^{-3} and US\$22.00 m^{-3}. Therefore, only 3 out of the 15 studied situations suggest economic unfeasibility, which confirms the significant contribution of woodchips to the project feasibility. The analysis also shows that a better negotiation with the reforestation company, or with the company from which the woodchopper is rent, can be enough to make the simulation with the firewood cost of US\$ 22.00 m^{-3} and land value of US\$ 3,000.00 ha^{-1} economically viable.

In case 3, the only unfeasible case occurred for the land price of US\$3,000.00 ha^{-1} with the firewood cost of US\$19.00 m^{-3}, which shows that agricultural residue complementary to woodchips improves the economic feasibility of the project since there were 3 unfeasible scenarios in case 2, and 8 in case 1, out of the 15 simulations. Therefore, agricultural biomass residue combined with woodchips is an attractive alternative for producers who seek to maintain the minimum of the reforestation area, and it is also a strategy adopted mainly in places where the land price is high.

Table 4. Economic analysis results for the studied cases

Land price (US\$/ha)	**Firewood (US\$/m³)**	**NPV (US\$)**		
		Case 1	**Case 2**	**Case 3**
1,000.00	19.00	616.34	2,104.59	2,575.33
	22.00	2,268.62	3,660.42	3,988.55
	25.00	3,920.90	5,216.25	5,401.77
1,500.00	19.00	-663.66	1,132.59	1,732.83
	22.00	988.62	2,688.42	3,146.05
	25.00	2,640.90	4,244.25	4,559.27
2,000.00	19.00	-1,943.66	160.59	890.33
	22.00	-291.38	1,716.42	2,303.55
	25.00	1,360.90	3,272.25	3,716.77
2,500.00	19.00	-3,223.66	-811.41	47.83
	22.00	-1,571.38	744.42	1,461.05
	25.00	80.90	2,300.25	2,874.27
3,000.00	19.00	-4,503.66	-1,783.41	-794.67
	22.00	-2,851.38	-227.58	618.55
	25.00	-1,199.10	1,328.25	2,031.77

Other factors indirectly linked to the results of this research can affect the project viability, such as the reforestation site in the property and some other advantages resulting from self-sufficiency in thermal energy. Although there is no specific data on land use by each producer in Brazil, we can consider that, in many cases, the full extent of the property is not used only for planting. There are unproductive areas, ravines, and slopes, which may be used for eucalyptus reforestation, without reducing grain production. In addition, considering a revenue (of corn production, for instance) of approximately US$225,000.00 per year, according to IBGE (Indicadores IBGE…, 2022), in a crop of 100 ha, the negative NPV of the reforestation would be, at the worst situation, US$4,503.66, which represents about 2% of the revenue and a minimal loss compared to the benefit of energy independence. Reforestation practice would also prevent problems with price variations, shipping, availability of products, and possible firewood delivery delays. It is important to ensure that drying is performed during the harvest season, which is necessary for the good quality of the agricultural products during storage.

The sensitivity analysis considered land and firewood prices (Figure 1). The variation of 3% of firewood price could affect the NPV in up to US$ 363.50, while the same variation of land price could affect the NPV in up to US$ 153.60. Therefore, firewood price has more influence on the economic analysis than the land price. The use of agricultural residue in case 3 does not significantly alter the sensitivity analysis profile, in comparison with the use of agricultural residue in case 1 and case 2, reinforcing the idea that agricultural residue should be used only by producers to maximize the cultivated area, that is, to minimize reforestation.

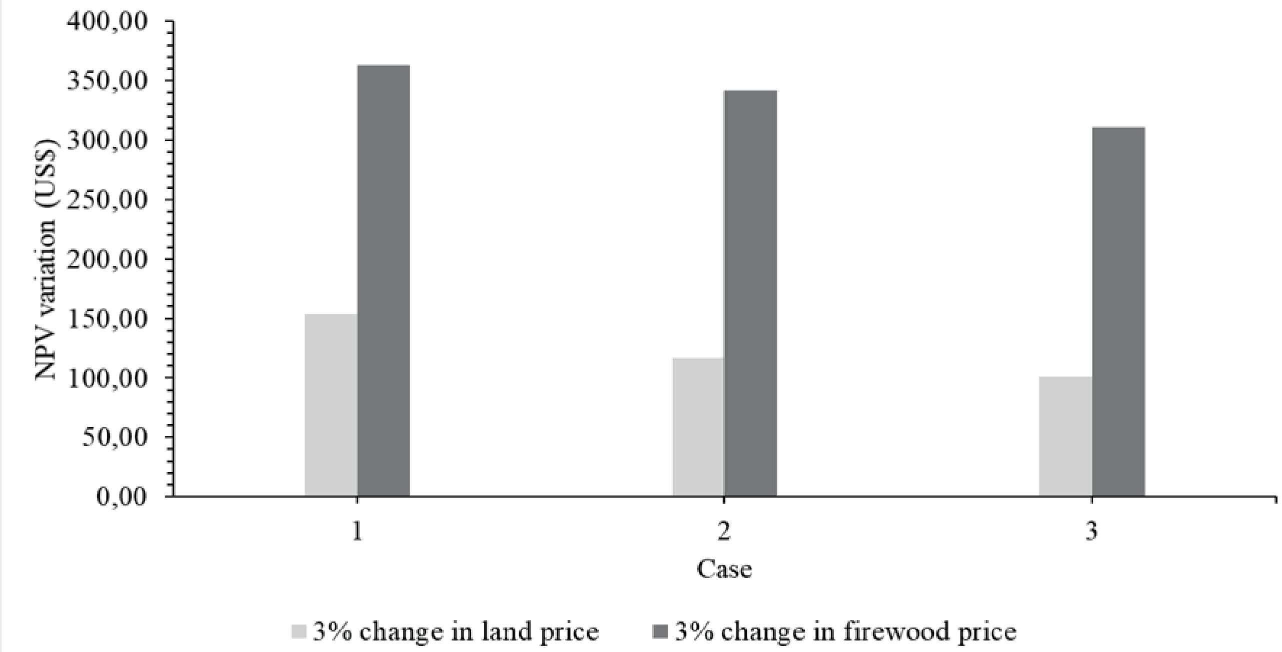

Figure 1. Sensitivity analysis of 3% considering land and firewood prices.

Since Brazil has a territorial extension of about 8.5 million km^2 (Indicadores IBGE…, 2022), it can also be possible a variation of land and firewood prices, making them different from those considered in this research. The results of economic analysis for possible variations in land and firewood prices are presented separately (Table 5). As expected, according to the sensitivity analysis, variations of firewood price caused more changes in the economic viability. It can be highlighted that the price below US$17.10 m^{-3} for firewood would make reforestation economically unfeasible for any land with a price above US$2,000.00 ha^{-1} in any studied case. Even with firewood price of US$16.15 m^{-3}, the use of crop residue would keep the reforestation economically feasible for lands with a price up to US$1,500.00 ha^{-1}. In addition, the firewood price of US$27.50 m^{-3} would turn all the studied situations economically feasible in any of the three cases. As expected, land prices below US$1,000.00 ha^{-1} would make all the studied cases economically feasible, and a land price of US$3,450.00 ha^{-1} would change the economic viability of only one situation, in case 3, with a firewood price of US$22.00 m^{-3}.

The variety of eucalyptus used for reforestation would significantly affect the reforestation area and the economic analysis results. Currently, research projects in the literature show specific properties of different species of trees. In their research, Eufrade Junior et al. (2017) showed eucalyptus trees with a higher value of inferior calorific power that is, above 15.6 kJ kg^{-1}. Used for the attainment of energetic self-sufficiency in the drying of agricultural products, these eucalyptus trees would make this practice even more advantageous. Thus, the study of new planting techniques and species characteristics can contribute to the viability of reforestation for thermal energy purposes. According to Paraná (2018), in the 2005-2015 period, firewood and land prices were different. Land price had not significantly increased, but firewood price increased about 50%. Therefore, it is also essential to consider the present economic scenario. However, considering a 2005-2015 inflation increase of 87% (Oliveira, 2016), it cannot be assumed that this project would not be viable in 2005. Cost variations higher than inflation would affect the viability of the reforestation project.

Table 5. Economic analysis results considering a possible variation in land and firewood prices

Firewood							
Case	Land price (US$/ha)	NPV (US$)					
		Change in min firewood price			Change in max firewood price		
		-5%	-10%	-15%	+5%	+10%	+15%
1	1000.00	93.12	-430.10	-953.33	4609.35	5297.80	5986.25
	1500.00	-1186.88	-1710.10	-2233.33	3329.35	4017.80	4706.25
	2000.00	-2466.88	-2990.10	-3513.33	2049.35	2737.80	3426.25
	2500.00	-3746.88	-4270.10	-4793.33	769.35	1457.80	2146.25
	3000.00	-5026.88	-5550.10	-6073.33	-510.65	177.80	866.25
2	1000.00	1611.91	1119.23	626.55	5864.51	6512.78	7161.04
	1500.00	639.91	147.23	-345.45	4892.51	5540.78	6189.04
	2000.00	-332.09	-824.77	-1317.45	3920.51	4568.78	5217.04
	2500.00	-1304.09	-1796.77	-2289.45	2948.51	3596.78	4245.04
	3000.00	-2276.09	-2768.77	-3261.45	1976.51	2624.78	3273.04
3	1000.00	2127.81	1680.29	1232.77	5990.61	6579.45	7168.29
	1500.00	1285.31	837.79	390.27	5148.11	5736.95	6325.79
	2000.00	442.81	-4.71	-452.23	4305.61	4894.45	5483.29
	2500.00	-399.69	-847.21	-1294.73	3463.11	4051.95	4640.79
	3000.00	-1242.19	-1689.71	-2137.23	2620.61	3209.45	3798.29

Land							
Case	Firewood price (US$/m^3)	NPV (US$)					
		Change in min land price			Change in max land price		
		-5%	-10%	-15%	+5%	+10%	+15%
1	19.00	744.34	872.34	1000.34	-4887.66	-5271.66	-5655.66
	22.00	2396.62	2524.62	2652.62	-3235.38	-3619.38	-4003.38
	25.00	4048.90	4176.90	4304.90	-1583.10	-1967.10	-2351.10
2	19.00	2201.79	2298.99	2396.19	-2075.01	-2366.61	-2658.21
	22.00	3757.62	3854.82	3952.02	-519.18	-810.78	-1102.38
	25.00	5313.45	5410.65	5507.85	1036.65	745.05	453.45
3	19.00	2659.58	2743.83	2828.08	-1047.42	-1300.17	-1552.92
	22.00	4072.80	4157.05	4241.30	365.80	113.05	-139.70
	25.00	5486.02	5570.27	5654.52	1779.02	1526.27	1273.52

The main objective of the economic analysis was to show that it was possible to eliminate the import dependency on firewood, from outside the farm, for drying. This objective is commonly present in research works on biomass, whose authors affirm that when energy for a process comes from the same region, it generates job opportunities and increases the local economy (He et al., 2016; Jackson et al., 2018). These authors showed an employment increase of 218 to 1127 jobs related to energy production from biomass in a rural area in central Appalachia, and the creation of more than 1500 jobs in the Southern U.S. The use of biomass, as proposed by He et al. (2016) and Jackson et al. (2018), contributes to the economic growth. Economic growth occurred in nine out of the ten analyzed countries which use biomass for energy purposes, and it was mainly observed for developing countries, such as Brazil, according to the findings by Bildirici (2013).

Transportation is another crucial factor for biofuel production since transport infrastructure costs in the biomass business (Figure 2 a) are very high (Ahl et al., 2018). A similar transport infrastructure model is presented by Whalley et al. (2017) and Paolotti et al. (2017), who state that due to the high costs associated with transportation and logistics, woody biomass businesses rely heavily on the supply chain. The present research proposed that shorter transport distances make the process even more economical and independent. One of the most significant advantages of using local reforestation is the smaller dependency on the transport infrastructure. A transport infrastructure is proposed in the present work (Figure 2 b).

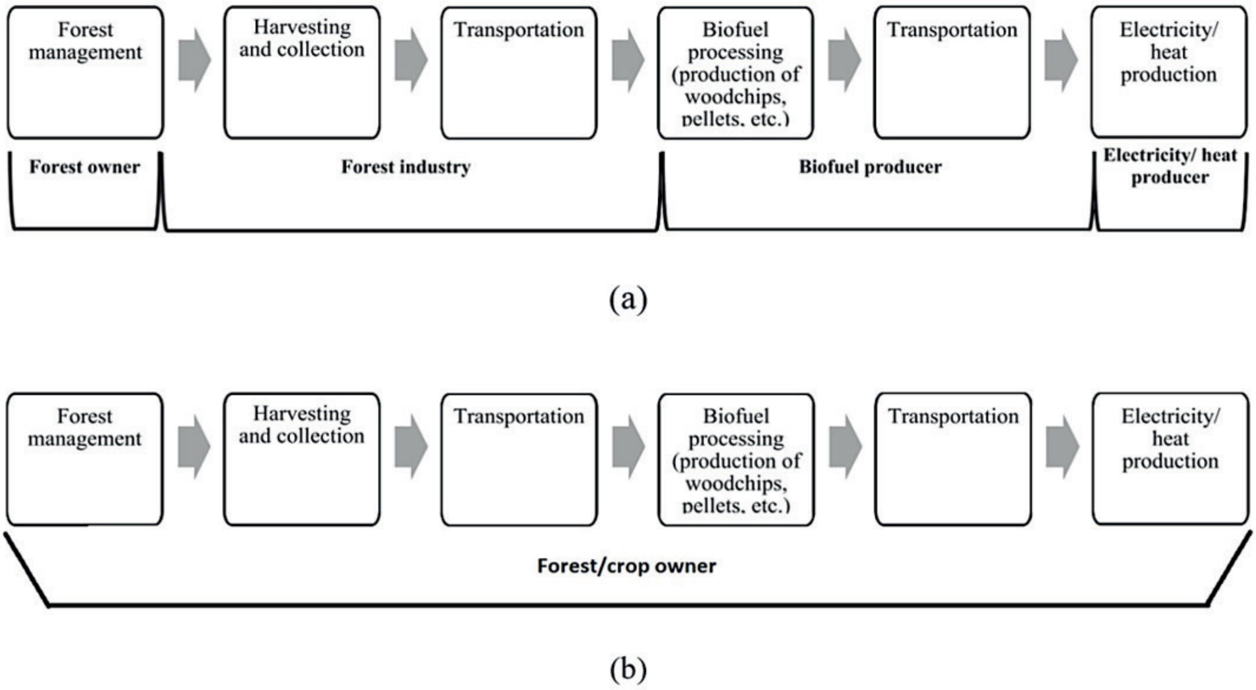

Figure 2. (A) Traditional woody biomass supply chain. (B) Proposed woody biomass supply chain. Source: adapted by Ahl et al. (2018).

Differently from the present research, Mola-Yudego et al. (2017) indicate that wood in logs is more advantageous in reforestation for heat purposes and consider that wood should be produced separately from the process place. Besides, the price of firewood in Italy is different from that in Brazil. Conversely, the present research considers that woodchips can be made through forest chopper rent from woods, using part of the farm for reforestation. It was also considered that part of the area usually used for grain production would be used for reforestation. Thus, these studies have a similar subject matter but different objectives and application profiles. The present research proves that the use of woodchips brings significant economic advantage for the producer who adopts reforestation in his crop.

This work corroborates the idea that using reforestation for energy purposes is advantageous. The crop area required for reforestation is small, which is consistent with other results in the literature. In Bilgili et al. (2017), a vast woody biomass amount can be generated using only 5% of the agricultural land in northern Europe. The specific topic in the present research is new in the literature, and it displays very significant information for several research works involving biomass and its applications, as well as for agricultural producers who seek information on the improvements for their crops. Energy from biomass can become an acceptable policy for environmentally sustainable development. Biomass consumption promotes the economic growth, especially in the BRICS (Brazil, Russia, India, China, and South Africa (Shahbaz et al., 2016).

CONCLUSIONS

The present research considered five agricultural products, but the adopted methodology can be performed with several other crops. A minimal reforestation area is required to dry the grain produced at the farm – between 0.61% and 4.26% of the crop area. It is noteworthy that the owner can choose a less fertile land to implant the eucalyptus forestry.

The use of woodchips and agricultural residue significantly contributes to the feasibility of reforestation practices in cultivations aiming at energy self-sufficiency for the drying of agricultural products. Negotiations about prices, mainly for firewood, can make a project economically viable.

Implementing reforestation projects in part of the crop areas is advantageous, even with a negative NPV. Since energy self-sufficiency for the drying of agricultural products is the primary goal, the economic unfeasibility does not imply that a project is not recommendable to be implemented.

It is believed that the proposed use of biomass can promote social benefits, such as job generation and regional economic growth, besides sustainable development, and some level of energy independence.

ACKNOWLEDGMENTS

To Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Coodenação de Apoio a Pessoal de Nível Superior (CAPES, Financial Code 001), for financial support.

REFERENCES

ACI. Associação Comercial, Industrial e de Serviços de Novo Hamburgo, Campo Bom e Estancia Velha. **Cotação do dólar**. 2022. Available at: <http://www.acinh.com.br/servicos/cotacao-dolar>. Accessed on: Feb. 22 2022.

ACOMPANHAMENTO DA SAFRA BRASILEIRA [DE] GRÃOS: safra 2015/2016: décimo segundo levantamento, v.3, n.12, set. 2016. Available at: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos/item/download/1305_92934803e5c32864b0ca922bb93bfc34>. Accessed on: Feb. 16 2022.

AFONSO JÚNIOR, P.C.; OLIVEIRA FILHO, D.; COSTA, D.R. Viabilidade econômica de produção de lenha de eucalipto para secagem de produtos agrícolas. **Engenharia Agrícola**, v.26, p.28-35, 2006. DOI: https://doi.org/10.1590/S0100-69162006000100004.

AHL, A.; EKLUND, J.; LUNDQVIST, P.; YARIME, M. Balancing formal and informal success factors perceived by supply chain stakeholders: a study of woody biomass energy systems in Japan. **Journal of Cleaner Production**, v.175, p.50-59, 2018. DOI: https://doi.org/10.1016/j.jclepro.2017.11.108.

ANUÁRIO ESTATÍSTICO DO BRASIL 2021. Rio de Janeiro: IBGE, 2022. Available at: <http://biblioteca.ibge.gov.br/visualizacao/periodicos/20/aeb_2021.pdf>. Accessed on: Apr. 30 2022.

AVILA, C.F. de J.; BESTER, A.U. Custos para reflorestamento de um hectare com *Eucalyptus grandis* W. Hill ex Maiden. In: SEMINÁRIO DE INICIAÇÃO CIENTÍFICA, 25.; JORNADA DE PESQUISA, 22; JORNADA DE EXTENSÃO, 18.; MOSTRA DE INICIAÇÃO CIENTÍFICA JÚNIOR, 7.; SEMINÁRIO DE INOVAÇÃO E TECNOLOGIA,7., 2017, Ijuí. **Anais**. Ijuí: Unijuí,

2017. Salão do Conhecimento. Available at: <https://www.publicacoeseventos.unijui.edu.br/index.php/salao conhecimento/article/view/7877/6613>. Accessed on: Apr. 11 2022.

BHUTTO, A.W.; QURESHI, K.; ABRO, R.; HARIJAN, K.; ZHAO, Z.; BAZMI, A.A.; ABBAS, T.; YU, G. Progress in the production of biomass-to-liquid biofuels to decarbonize the transport sector – prospects and challenges. **RSC Advances**, v.6, p.32140-32170, 2016. DOI: https://doi.org/10.1039/C5RA26459F.

BILDIRICI, M.E. Economic growth and biomass energy. **Biomass and Bioenergy**, v.50, p.19-24, 2013. DOI: https://doi.org/10.1016/j.biombioe.2012.09.055.

BILGILI, F.; KOÇAK, E.; BULUT, Ü.; KUSKAYA, S. Can biomass energy be an efficient policy tool for sustainable development? **Renewable and Sustainable Energy Reviews**, v.71, p.830-845, 2017. DOI: https://doi.org/10.1016/j.rser.2016.12.109.

BURGESS, P.J.; CASADO, M.R.; GAVU, J.; MEAD, A.; COCKERILL, T.; LORD, R.; van der HORST, D.; HOWARD, D.C. A framework for reviewing the trade-offs between, renewable energy, food, feed and wood production at a local level. **Renewable and Sustainable Energy Reviews**, v.16, p.129-142, 2012. DOI: https://doi.org/10.1016/j.rser.2011.07.142.

CHEN, X. Economic potential of biomass supply from crop residues in China. **Applied Energy**, v.166, p.141-149, 2016. DOI: https://doi.org/10.1016/j.apenergy.2016.01.034.

CHICHORRO, J.F.; SILVA, A.L.P. da; ANDRADE, W.S. de P.; HEGEDUS, C.E.N.; KUBOYAMA, F.A.Q. Custos e índices econômicos de povoamentos de eucalipto do Programa Produtor Florestal no Espírito Santo. **Pesquisa Florestal Brasileira**, v.37, p.447-456, 2017. DOI: https://doi.org/10.4336/2017.pfb.37.92.1232.

DERCAN, B.; LUKIĆ, T.; BUBALO-ŽIVKOVIĆ, M.; DURDEV, B.; STOJSAVLJEVIĆ, R.; PANTELIĆ, M. Possibility of efficient utilization of wood waste as a renewable energy resource in Serbia. **Renewable and Sustainable Energy Reviews**, v.16, p.1516-1527, 2012. DOI: https://doi.org/10.1016/j.rser.2011.10.017.

DESIDERIO, V.M. **Análise de custos de um projeto de silvicultura de *Eucalyptus* spp. de uma empresa de base florestal do Estado do Paraná**. 2021. 78f. Trabalho de Conclusão de Curso (Graduação) - Universidade Federal do Paraná, Curitiba. Available at: <https://acervodigital.ufpr.br/bitstream/handle/1884/73421/R_G_VIVIAN_MUSSOLINI_DESIDERIO.pdf?sequence=1&isAllowed=y>. Accessed on: Apr. 12 2022.

DUARTE, A.; SARACHE, W.; COSTA, Y. Biofuel supply chain design from Coffee Cut Stem under environmental analysis. **Energy**, v.100, p.321-331, 2016. DOI: https://doi.org/10.1016/j.energy.2016.01.076.

DUARTE, I. Brasil recebe cargas de fertilizantes da Rússia, mas risco de escassez se mantém. **Jornal Estadão - Economia e Negócios**, 29 abr. 2022. Available at: <https://economia.estadao.com.br/noticias/geral,brasil-importacao-fertilizantes-russia-risco-escassez,70004052461>. Accessed on: June 28 2022.

EUFRADE JUNIOR, H. de J.; NAKASHIMA, G.T.; YAMANJI, F.M.; GUERRA, S.P.S.; BALLARIN, A.W. Eucalyptus short-rotation coppice for solid fuel production. **Industrial Crops & Products**, v.108, p.636-640, 2017. DOI: https://doi.org/10.1016/j.indcrop.2017.07.025.

GOLECHA, R.; GAN, J. Biomass transport cost from field to conversion facility when biomass yield density and road network vary with transport radius. **Applied Energy**, v.164, p.321-331, 2016. DOI: https://doi.org/10.1016/j.apenergy.2015.11.070.

GUO, S.; WANG, Q.; HORDOFA, T.T.; KAUR, P.; NGUYEN, N.Q.; MANEENGAM, A. Does COVID-19 pandemic cause natural resources commodity prices volatility? Empirical evidence from China. **Resources Policy**, v.77, art.102721, 2022. DOI: https://doi.org/10.1016/j.resourpol.2022.102721.

HE, L.; ENGLISH, B.C.; MENARD, R.J.; LAMBERT, D.M. Regional woody biomass supply and economic impacts from harvesting in the southern U.S. **Energy Economics**, v.60, p.151-161, 2016. DOI: https://doi.org/10.1016/j.eneco.2016.09.007.

HU, H.; LI, Z.; JIANG, Y.; DU, X. Thermodynamic characteristics of thermal power plant with hybrid (dry/wet) cooling system. **Energy**, v.147, p.729-741, 2018. DOI: https://doi.org/10.1016/j.energy.2018.01.074.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Cidades e Estados**. 2021. Available at: <https://www.ibge.gov.br/cidades-e-estados.html>. Accessed on: Dec. 12 2021.

INDICADORES IBGE: levantamento sistemático da produção agrícola: estatística da produção agrícola. Rio de Janeiro: IBGE, mar. 2022. Available at: <https://ftp.ibge.gov.br/Producao_Agricola/Levantamento_Sistematico_da_Producao_Agricola_%5Bmensal%5D/Fasciculo_Indicadores_IBGE/2022/estProdAgri_202203.pdf>. Accessed on: June 16 2023.

JACKSON, R.W.; FERREIRA NETO, A.B.; ERFANIAN, E. Woody biomass processing: Potential economic impacts on rural regions. **Energy Policy**, v.115, p.66-77, 2018. DOI: https://doi.org/10.1016/j.enpol.2018.01.001.

KAIDA, R.; KAKU, T.; BABA, K.; HARTATI, S.; SUDARMONOWATI, S.H.E.; HAYASHI, T. Enhancement of saccharification by overexpression of poplar cellulase in sengon. **Journal of Wood Science**, v.55, p.435-440, 2009. DOI: https://doi.org/10.1007/s10086-009-1048-y.

KAPLAN, O.; CELIK, C. An experimental research on woodchip drying using a screw conveyor dryer. **Fuel**, v.215, p.468-473, 2018. DOI: https://doi.org/10.1016/j.fuel.2017.11.098.

MANZONE, M. Loader performance during woodchip loading. **Biomass and Bioenergy**, v.98, p.80-84, 2017. DOI: https://doi.org/10.1016/j.biombioe.2017.01.016.

MAZUI, G. Novo Plano Safra é anunciado com mais recursos e alta nos juros. **GZH Campos & Lavoura**, 2 jun. 2015. Available at: <https://gauchazh.clicrbs.com.br/economia/campo-e-lavoura/noticia/2015/06/novo-plano-safra-e-anunciado-com-mais-recursos-e-alta-nos-juros-4773318.html>. Accessed on: July 20 2022.

MFRURAL. Mercado Físico Rural. **Aluguel de picador de cavacos**. Available at: <https://www.mfrural.com.br/busca/aluguel-picador-cavaco>. Accessed on: May 4 2022.

MOLA-YUDEGO, B.; AREVALO, J.; DÍAZ-YAÑEZ, O.; DIMITRIOU, I.; HAAPALA, A.; FERRAZ FILHO, A.C.; SELKIMÄKI, M.; VALBUENA, R. Wood biomass potentials for energy in northern Europe: forest or plantations? **Biomass and Bioenergy**, v.106, p.95-103, 2017. DOI: https://doi.org/10.1016/j.biombioe.2017.08.021.

MOREIRA, J.M.M.A.P.; SANTOS, A.M.; REIS, C.A.F.; SIMIONI, F.J.; OLIVEIRA, V.L.E. de. 2021. **Viabilidade econômica de eucalipto para energia em Cristalina, Goiás**. Colombo: Embrapa Florestas, 2021. 35p. (Embrapa Florestas. Documentos, 352).

MOYA, R.; TENORIO, C.; OPORTO, G. Short rotation wood crops in Latin American: a review on status and potential uses as biofuel. **Energies**, v.12, art.705, 2019. DOI: https://doi.org/10.3390/en12040705.

NASCIMENTO, M.D. do; BIAGGIONI, M.A.M. Avaliação energética do uso de lenha e cavaco de madeira para produção de energia em agroindústria seropédica. **Energia na Agricultura**, v.25, p.104-117, 2010. DOI: https://doi.org/10.17224/EnergAgric.2010v25n3p104-117.

OLIVEIRA, N. de. IPCA: inflação official fecha 2015 em 10,67%. **AgênciaBrasil**, 8 jan. 2016. Available at: <http://agenciabrasil.ebc.com.br/economia/noticia/2016-01/ipca-inflacao-oficial-fecha-2015-em-maior-alta-desde>. Accessed on: Feb. 25 2022.

ONWUDE, D.I.; HASHIM, N.; CHEN, G. Recent advances of novel thermal combined hot air drying of agricultural crops. **Trends in Food Science & Technology**, v.57, p.132-145, 2016. DOI: https://doi.org/10.1016/j.tifs.2016.09.012.

PANDEY, A.; SOCCOL, C.R.; NIGAM, P.; BRAND, D.; MOHAN, R.; ROUSSOS, S. Biotechnological potential of coffee pulp and coffee husk for bioprocesses. **Biochemical Engineering Journal**, v.6, p.153-162, 2000. DOI: https://doi.org/10.1016/S1369-703X(00)00084-X.

PAOLOTTI, L.; MARTINO, G.; MARCHINI, A.; BOGGIA, A. Economic and environmental assessment of agro-energy wood biomass supply chains. **Biomass and Bioenergy**, v.97, p.172-185, 2017. DOI: https://doi.org/10.1016/j.biombioe.2016.12.020.

PARANÁ. Secretaria da Agricultura e do Abastecimento. [**Histórico semestral de preços florestais**]. 2018. Available at: <https://www.agricultura.pr.gov.br/Pagina/Precos-de-Produtos-Florestais>. Accessed on: Feb. 14 2022.

REINATO, C.H.R.; BORÉM, F.M.; VILELA, E.R.; CARVALHO, F.M.; MEIRELES, E. de P. Consumo de energia e custo de secagem de café cereja em propriedades agrícolas do sul de Minas Gerais. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.6, p.112-116, 2002. DOI: https://doi.org/10.1590/S1415-43662002000100020.

RODRIGUES, B. Rússia mantém envio de fertilizantes para o Brasil apesar da guerra, diz Ministério da Agricultura. **CNN Brasil**, 9 mar. 2022. Available at: <https://www.cnnbrasil.com.br/business/russia-mantem-envio-de-fertilizantes-para-o-brasil-apesar-da-guerra-diz-ministerio-da-agricultura/>. Accessed on: June 28 2022.

SCHWANTES, F.; ARAÚJO, L.M. de. **Síntese do Plano Agrícola e Pecuário 2021/2022**. Brasília: CNA, 2021. (CNA. Nota técnica, nº15). Available at: <https://www.cnabrasil.org.br/assets/arquivos/artigostecnicos/CNA-Nota-Tecnica-n15-2021.pdf>. Accessed on: Feb. 28 2022.

SHAHBAZ, M.; RASOOL, G.; AHMED, K.; MAHALIK, M.K. Considering the effect of biomass energy consumption on economic growth: fresh evidence from BRICS region. **Renewable and Sustainable Energy Reviews**, v.60, p.1442-1450, 2016. DOI: https://doi.org/10.1016/j.rser.2016.03.037 .

SILVA, C.M.S. da; CARNEIRO, A. de C.O.; VITAL, B.R.; FIGUEIRÓ, C.G.; FIALHO, L. de F.; MAGALHÃES, M.A. de; CARVALHO, A.G.; CÂNDIDO, W.L. Biomass torrefaction for energy purposes – Definitions and an overview of challenges and opportunities in Brazil. **Renewable and Sustainable Energy Reviews**, v.82, p.2426-2432, 2018. DOI: https://doi.org/10.1016/j.rser.2017.08.095.

SINGH, J.; PANESAR, B.S.; SHARMA, S.K. A mathematical model for transporting the biomass to biomass based power plant. **Biomass and Bioenergy**, v.34, p.483-488, 2010. DOI: https://doi.org/10.1016/j.biombioe.2009.12.012.

TIMMONS, D.; MEJÍA, C.V. Biomass energy from wood chips: Diesel fuel dependence? **Biomass and Bioenergy**, v.34, p.1419-1425, 2010. DOI: https://doi.org/10.1016/j.biombioe.2010.04.010.

TOKLU, E. Biomass energy potential and utilization in Turkey. **Renewable Energy**, v.107, p.235-244, 2017. DOI: https://doi.org/10.1016/j.renene.2017.02.008.

TOLMASQUIM, M.T.; GUERREIRO, A.G. (Coord.). **Nota técnica DEA 15/14**: Inventário Energético de Resíduos Rurais. Rio de Janeiro: EPE, 2014. p.12-22. (EPE. Recursos Energéticos). Available at: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-251/topico-308/DEA%2015%20-%2014%20-%20%20Invent%C3%A1rio%20Energ%C3%A9tico%20de%20Res%C3%ADduos%20Rurais%5B1%5D.pdf>. Accessed on: June 20 2023.

UDOMKUN, P.; ROMULI, S.; SCHOCK, S.; MAHAYOTHEE, B.; SARTAS, M.; WOSSEN, T.; NIJUKWE, E.; VANLAUWE, B.; MÜLLER, J. Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. **Journal of Environmental Management**, v.268, art.110730, 2020. DOI: https://doi.org/10.1016/j.jenvman.2020.110730.

VERMA, M.; LOHA, C.; SINHA, A.N.; CHATTERJEE, P.K. Drying of biomass for utilising in co-firing with coal and its impact on environment – a review. **Renewable and Sustainable Energy Reviews**, v.71, p.732-741, 2017. DOI: https://doi.org/10.1016/j.rser.2016.12.101.

WELFLE, A. Balancing growing global bioenergy resource demands - Brazil's biomass potential and the availability of resource for trade. **Biomass and Bioenergy**, v.105, p.83-95, 2017. DOI: https://doi.org/10.1016/j.biombioe.2017.06.011.

WHALLEY, S.; KLEIN, S.J.W.; BENJAMIN, J. Economic analysis of woody biomass supply chain in Maine. **Biomass and Bioenergy**, v.96, p.38-49, 2017. DOI: https://doi.org/10.1016/j.biombioe.2016.10.015.

WILLIAMS, O.; LESTER, E.; KINGMAN, S.; GIDDINGS, D.; LORMOR, S.; EASTWICK, C. Benefits of dry comminution of biomass pellets in a knife mill. **Biosystems Engineering**, v.160, p.42-54, 2017. DOI: https://doi.org/10.1016/j.biosystemseng.2017.05.011.