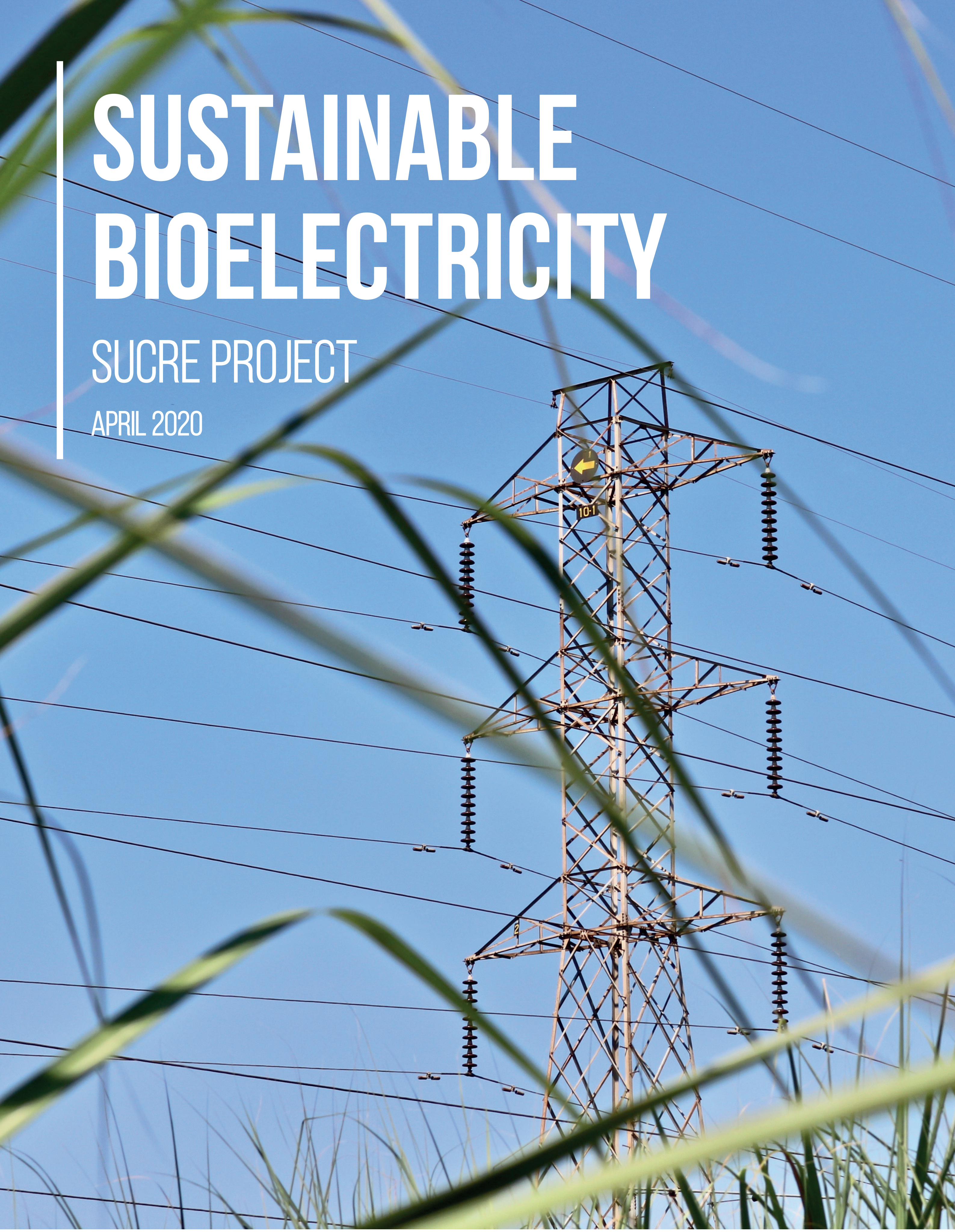
SUSTAINABLE BIOELECTRICITY

SUCRE PROJECT

APRIL 2020



UNDP
gef
GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET
SUCRE
lnbr
brazilian biorenewables national laboratory
CNPEM
Brazilian Center for Research in Energy and Materials

ABOUT SUCRE PROJECT

The SUCRE (Sugarcane Renewable Electricity) Project is primarily designed to **increase the production of electricity with low greenhouse gases (GHG) emission using the sugarcane straw** made available during the crop harvest. SUCRE team has been working on identifying and solving issues that hinder partner mills from fully and systematically generating electricity. Beginning in June 2015, it is a total five years of Project, with funding of around US$ 7.5 million from Global Environment Facility (GEF) and a counterpart from the Brazilian Center for Research in Energy and Materials (CNPEM) of over US$ 3 million. The recovery and use of straw for electricity production in the private sector triggered an investment of approximately US$ 160 million by partner plants (a major part of which has already been done through the installation of dry cleaning systems, refurbishment or purchase of boilers, turbogenerators, balers and other pieces of equipment). The initiative is managed through a partnership with the United Nations Development Programme (UNDP) and is carried out by the Brazilian Biorenewables National Laboratory (LNBR), which is part of CNPEM.

ABOUT LNBR

The Brazilian Biorenewables National Laboratory (LNBR) is part of the Brazilian Center for Research in Energy and Materials (CNPEM), a non-profit private organization that operates under Contract Management with the Brazilian Ministry of Science, Technology, Innovations and Communications (MCTIC). LNBR uses Brazilian biomass and biodiversity to solve key scientific and technological challenges by employing high-performance biological platforms of industrial relevance for the sustainable development of advanced biofuels, biochemicals and biomaterials. The Laboratory has a history of technology development in partnership with companies, including start-ups. Among LNBR open-access facilities one finds a Pilot Plant for Process Development, a unique facility for scaling up of technologies.

ABOUT CNPEM

The Brazilian Center for Research in Energy and Materials (CNPEM) is a non-profit private organization under supervision of the Brazilian Ministry of Science, Technology, Innovation and Communications (MCTIC). Located in Campinas, São Paulo, the Center is comprised of four laboratories, worldwide references in their fields, which are open to the scientific and business communities. The Brazilian Synchrotron Light Laboratory (LNLS) is currently assembling Sirius, the new Brazilian electron accelerator. The Brazilian Biosciences National Laboratory (LNBio) is dedicated to solving challenges in the areas of health. The Brazilian Biorenewables National Laboratory (LNBR) is focused on biotechnological solutions for the sustainable development of advanced biofuels, biochemicals and biomaterials, using biomass and the Brazilian biodiversity. Finally, the Brazilian Nanotechnology National Laboratory (LNNano) conducts scientific research and technologic development into solutions based on nanotechnology. The four Laboratories also have their own research projects and participate in the transversal research agenda coordinated by CNPEM, which articulates scientific facilities and capabilities around strategic themes.

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INTRODUCTION

Considering the importance of sustainability in defining the best ways to recover straw for generating bioelectricity, SUCRE Project has a stage for integrating the results. Here, all knowledge previously acquired by the team from experiments in the field and testing in the industry have been used to provide valuable information to the sugarcane industry. Integration helps in determining the environmental, economic and social impacts of using sugarcane straw to generate bioelectricity.

THE IMPORTANCE OF PREDICTING IMPACTS

It is vitally important that sugarcane mills are able to anticipate the economic and environmental outcomes before carrying out any straw recovery. This facilitates crucial decision making, allowing sugarcane mills to target their resources towards projects with sound economic and environmental potential. For example, knowing what kind of straw recovery is most suitable in the field or which equipment to use in the industry can be anticipated through computer calculations, in order to assess whether the decision may or may not be viable.

BUT HOW IS THIS ACCOMPLISHED?

SUCRE Project uses the **Virtual Sugarcane Biorefinery (VSB)**, designed by the Brazilian Biorenewables National Laboratory (LNBR), that integrates the Brazilian Center for Research in Energy and Materials (CNPEM). The VSB employs computational models as the primary tool in simulating possible situations, both in the field as well as in the industry. It is as if everything that takes place in a mill, from the production of sugarcane and industrial processing to the use of the generated products, is on a giant calculator. Calculations performed provide feedback on the potential economic, environmental and social impacts of the stages in the production process.

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A CUSTOM EVALUATION

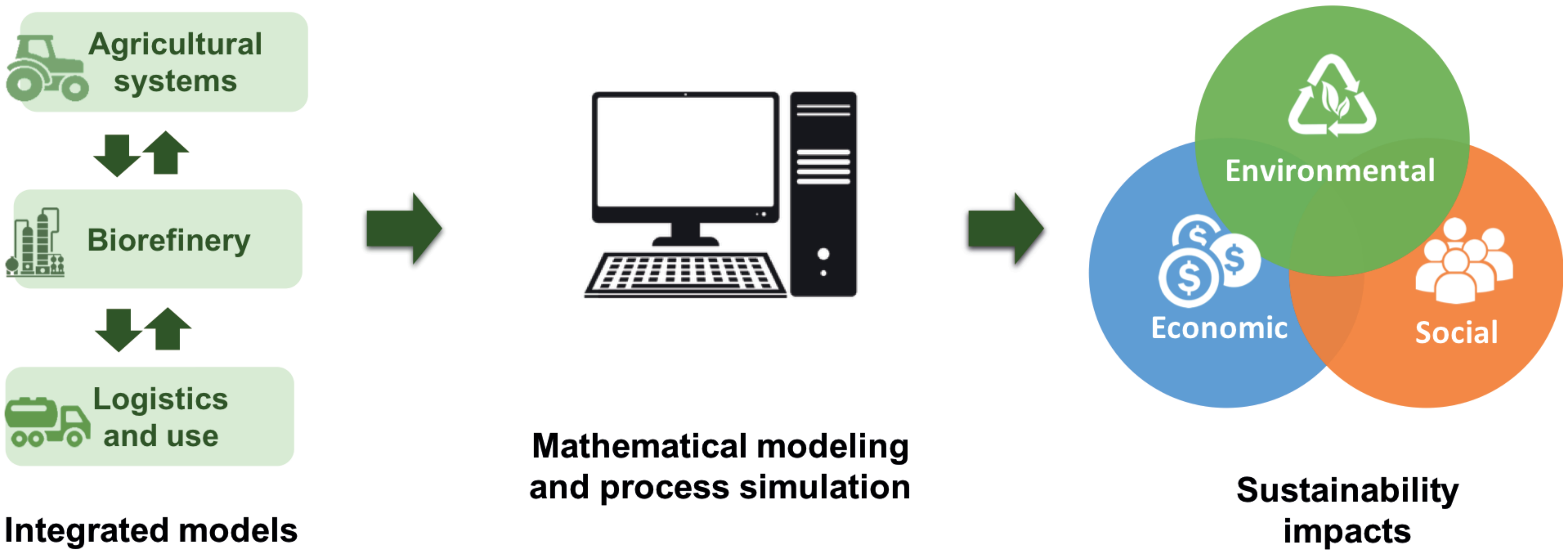
Given the wide variety of sugarcane mills participating in SUCRE Project, understanding the best way to handle and take advantage of the available straw was not an easy task. There are a number of factors that have an impact on the cost and quality of the straw recovered, from the productivity of the cane to the operational yield of the machinery used. In addition, there are a variety of factors at the industrial stage related to the impact of straw on the mill's industrial processes.

Throughout the five years of SUCRE Project,12 partner mills were appreised in an effort to provide insights to help in understanding whether the generation of electricity from sugarcane straw could yield satisfactory results in terms of sustainability.

In the first stage, we sought to map the operational characteristics of the four participating mills. As a result, the details of sugarcane production and straw recovery were assessed, with the calculations adjusted according to the characteristics of each participating mill. Similarly, processing in the industry was also detailed, with simulations adjusted according to the information received.

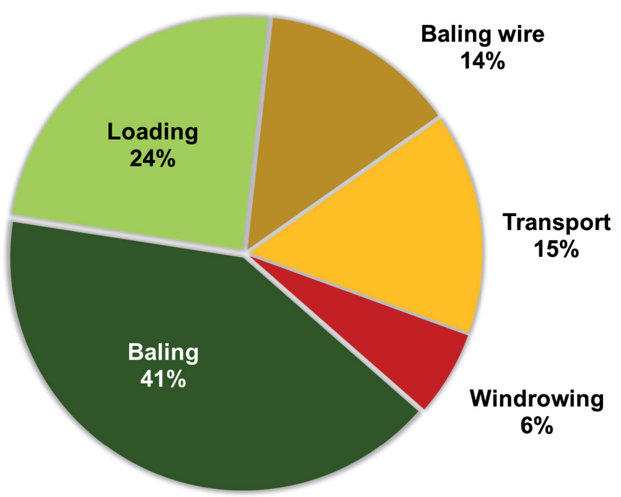
The second stage incorporated lessons learned from the previous stages of the Project and, along with eight new participating sugarcane mills, the Integration team defined the relevant scenarios for assessing the recovery and use of straw. The assessments were conducted using the VSB, adjusted for the current situation of each mill.

VIRTUAL SUGARCANE BIOREFINERY (VSB)

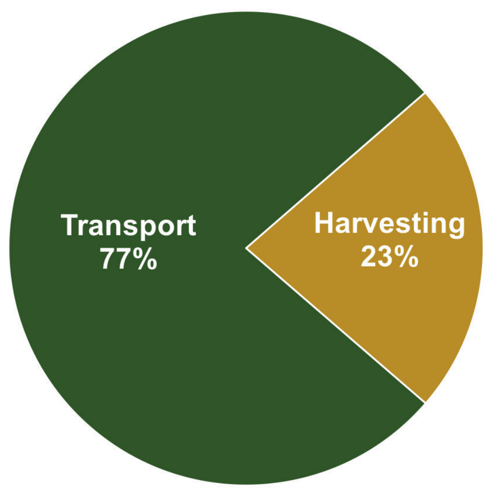


WHAT IS THE BEST SYSTEM FOR STRAW RECOVERY?

Average distribution of baling costs



Average distribution of integral harvesting costs

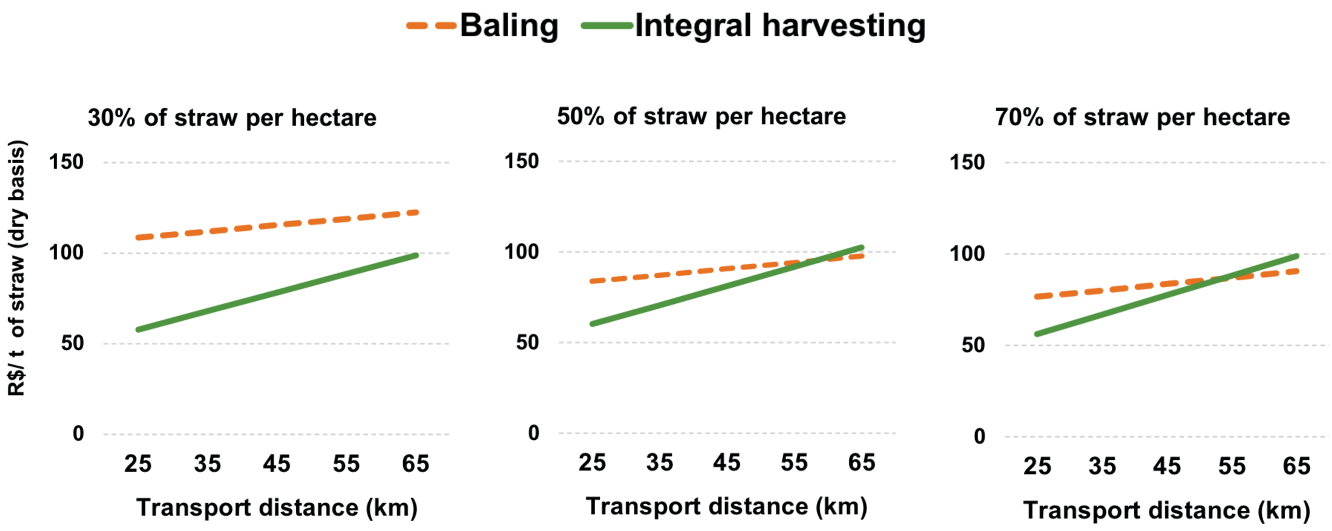


Considering the baling system, it was noted that the baling stage requires a great deal of attention because it accounts, on average, for more than 40% of the recovery cost. Another significant step is loading the bales, which can exceed 20% of the cost.

In the integral harvesting system, straw is recovered and transported along with the cane, in the same load. Thus, only the stages of recovery and transport are part of this recovery system. In this system, transport is the stage with the highest share in the cost of straw, which could represent up to 80%.

Each straw recovery system has advantages and disadvantages. As such, **specific conditions have to be considered** when choosing the most appropriate recovery system.

STRAW RECOVERY COSTS VARYING THE AMOUNT OF STRAW RECOVERED PER HECTARE AND THE TRANSPORT DISTANCE

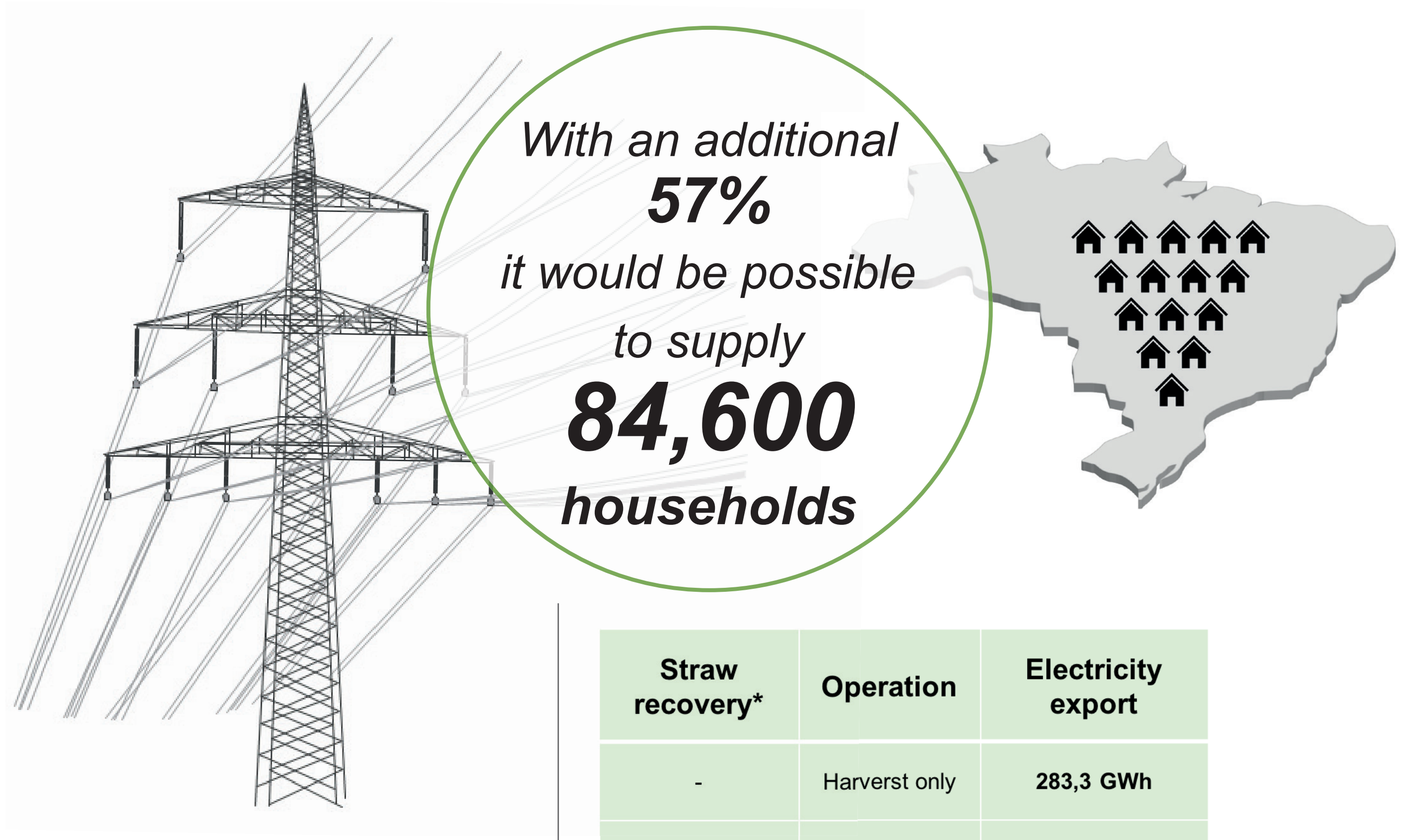


STRAW RECOVERY INCREASES THE EXPORT OF ELECTRICITY

Industrial simulations make it possible to calculate an increase in electricity generation from sugarcane mills that opt to recover straw. **A number of factors play a role in increased cogeneration**, notably equipment and their operating conditions. Turbines and boilers with higher temperature and pressure are required for greater cogeneration. **It should be pointed out that if the mill uses steam produced for other applications, such as stationary steam engines, generation of electricity will decrease**. Similarly to the agricultural stage, it is possible to evaluate the impacts of recovery systems (baling and integral harvesting) in the industrial stage. The chosen recovery system results in significant differences in the industrial configuration. Each system requires specific equipment, and the route of straw inside the sugarcane mill also varies. Using bales, the recovered straw is processed and sent directly to cogeneration, with no impact on sugar and ethanol production processes. In the case of integral harvesting system, a portion of straw is crushed along with sugarcane, which can result in losses during sugar extraction and, consequently, in the production of sugar and ethanol.

CALCULATING THE INCREASE IN THE EXPORT OF ELECTRICITY

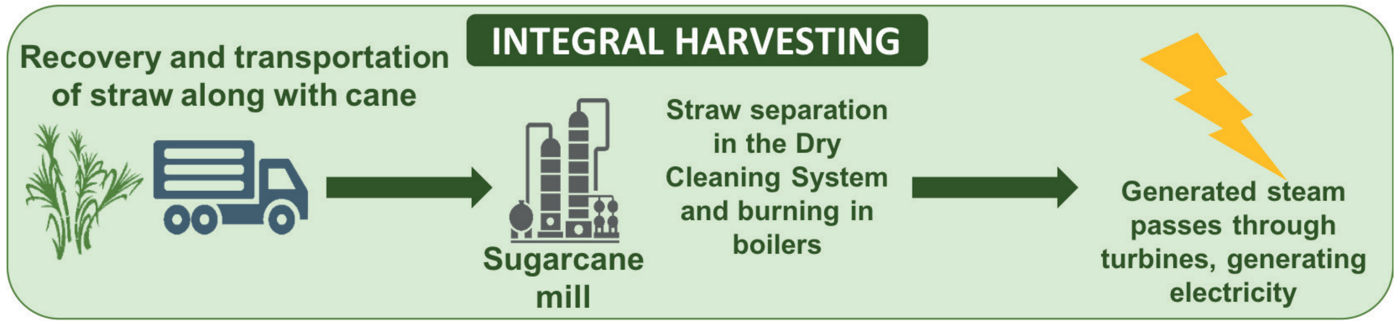
The increase in electricity exports associated to recovering straw can be simulated. Given that a generic sugarcane mill processes 4 million tonnes per year, a recovery of 9% straw produced in the field can increase its electricity export by 22%. By increasing the recovery to 27% and operating during the inter-harvest, exported electricity can increase by 57%. These results do not consider investments in new equipment and assume a 10% idle capacity in boilers and turbines. Straw processing and inter-harvest operations demand electricity. An energy consumption of 25 kW per tonne of processed straw for bales was adopted, and 8% of the electricity generated during interharvest is consumed to operate the mill. It is assumed that a extraction-condensing turbine operates at its maximum condensing capacity for interharvest. It should also be noted that, even considering these additional consumptions, the exported electricity is still significantly higher when straw is recovered.

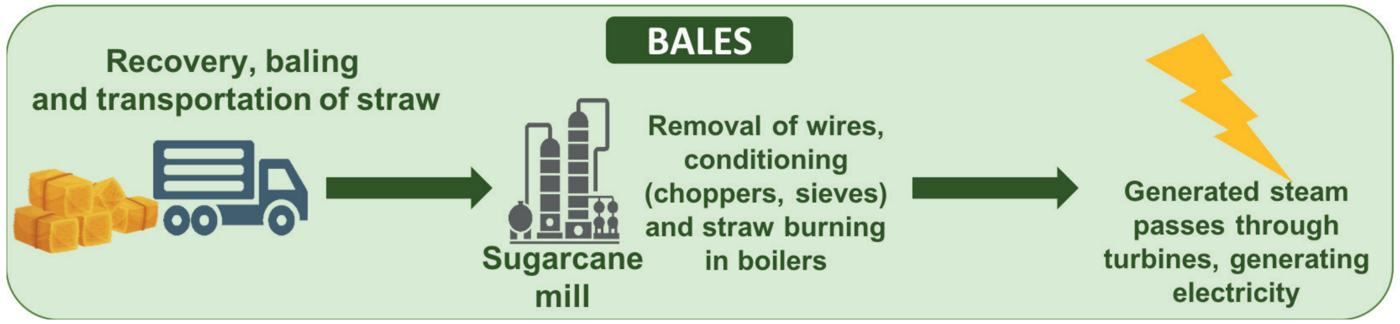


Processing: *4 million tonnes of sugarcane*
Boiler: *65 bar*
Recovery system: *bales*

Straw recovery*	Operation	Electricity export	
-	Harvest only	283,3 GWh	
9%	Harvest only	345,4 GWh	+ 22%
27%	Harvest + Inter-harvest	443,7 GWh	+ 57%

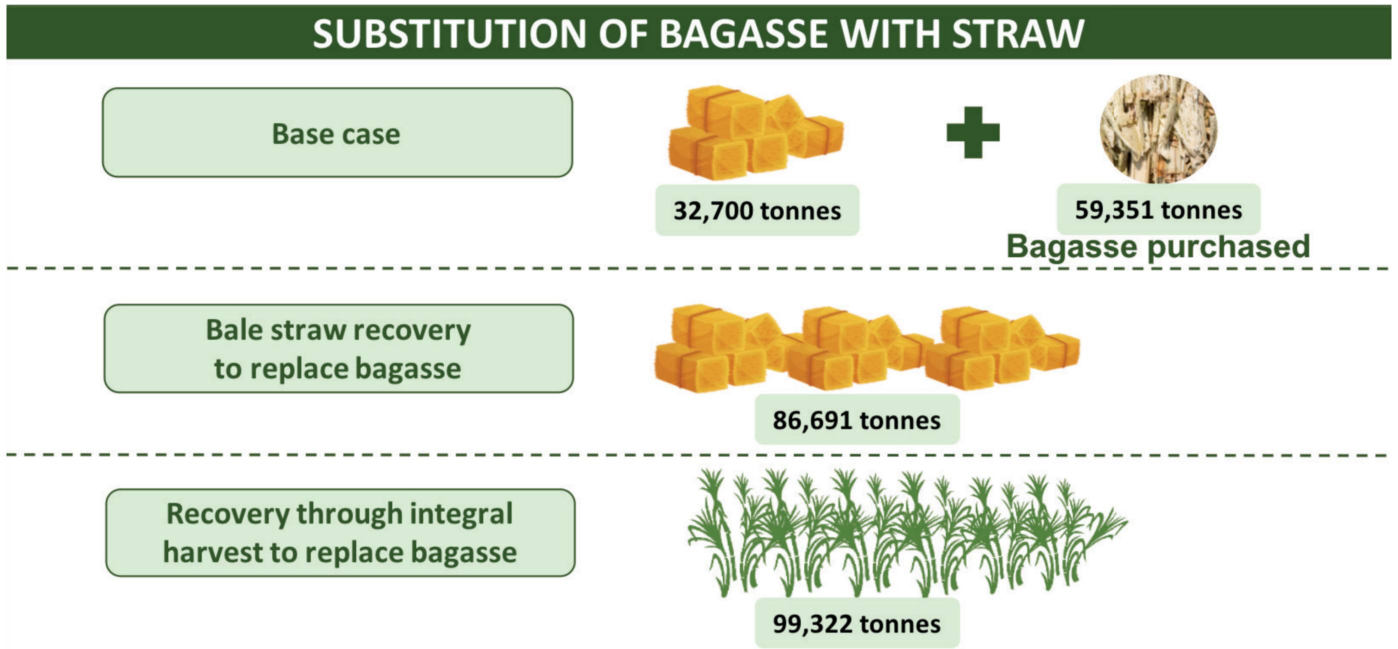
**Total straw produced in the field*





CALCULATING THE SUBSTITUTION OF BAGASSE WITH STRAW

The amount of straw recovered needed to replace the purchase of bagasse from another mill in order to maintain (or increase) the export of electricity can also be simulated. Assuming a sugarcane mill that purchases 59,351 tonnes of bagasse (dry basis) and already recovers 32,700 tonnes of straw (dry basis) to meet a contract to export 87,600 MWh, a total 86,691 tonnes of straw (dry basis) would need to be recovered per year through bales, or 99,322 tonnes (dry basis) per year through a integral harvesting system to avoid purchasing bagasse and keep exports at 87,600 MWh.



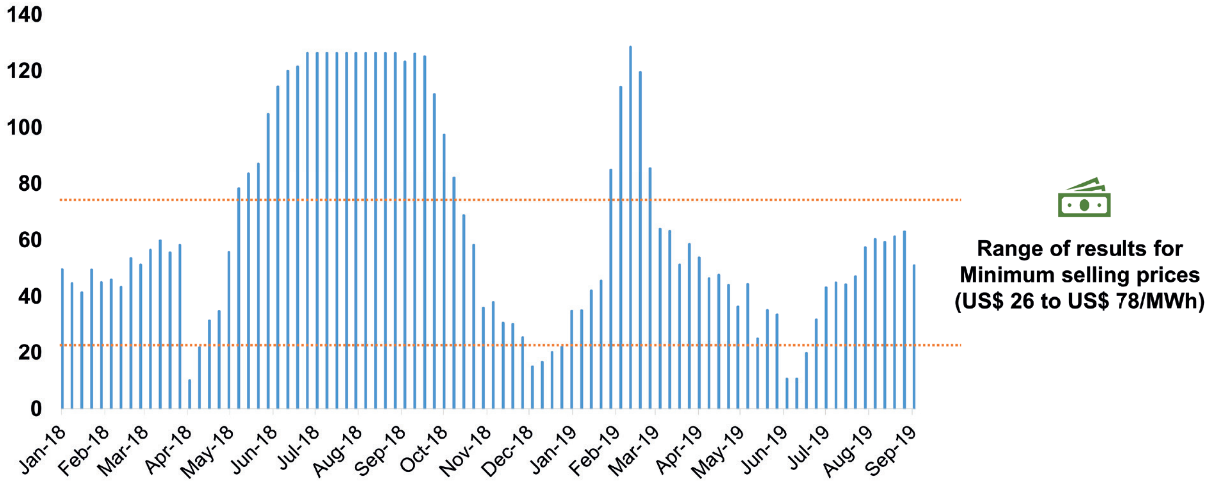
THE IMPORTANCE OF A MINIMUM SELLING PRICE FOR ELECTRICITY

in the viability of straw recovery projects

There is no single response for each assessment within the economic viability analysis. In other words, the straw recovery may or may not be feasible for real cases, which are subject to uncertainties. In this case, a step known as "sensitivity analysis" is done, which determines where the economic viability is in price and cost regions. For each sugarcane mill, different viability and non-viability regions are obtained, considering that the data gathered in the calculations depend on the aforementioned specific characteristics. The illustration below shows an example of viability when replacing bagasse purchased with straw. The more expensive the substituted bagasse and the lower the agricultural cost of the straw, the greater the chances of viability. Another example reveals that a similar effect occurs when the price of electricity is higher and when the cost of collecting straw by the power plant is lower.

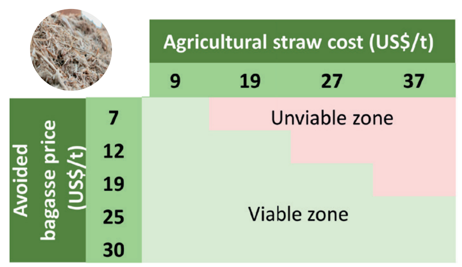
One of the most important indicators among the sensitivity analyses conducted with the Project's partner mills is the electricity minimum selling price, i.e., the value by which the investment made in the project is fully recovered. In the analyses, the minimum selling price ranged from US$ 26/MWh (best case) to US$ 78/MWh (worst case). As can be seen in the graph below, if the project targets prices in the spot market, there is a chance of getting more attractive prices, but that are subject to a lot of price fluctuations. An alternative in this instance may be the unregulated energy market (ACL), where contracts can provide more predictable prices in the short and medium term, deriving the benefits for incentivized sources of electricity. For long term electricity price predictability, auction contracts (ACR) are the most recommended. But, the historical average price for this type of contract has been at levels close to **US$ 50/MWh**.

WEEKLY ELECTRICITY PRICES | SPOT MARKET (US$/MWh)



Exchange rate US$ = R$ 4 *(CCEE, 2019)*

STRAW COSTS, PRICES FOR ELECTRICITY AND BAGASSE SPECIFIC TO AN ASSESSED CASE



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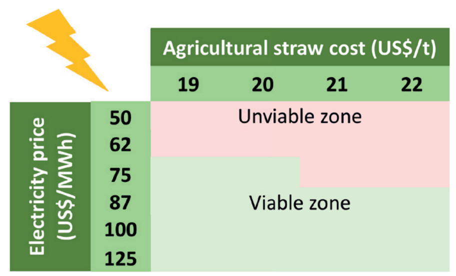


Exchange rate US$ = R$ 4

SUGARCANE BIOELECTRICITY CREATES JOBS AND YIELDS INCOME

The increase in electricity generation through the recovery of straw remaining in the field should also be analyzed as to its social effects. To produce more electricity using straw from sugarcane, additional workers are needed to gather straw in the field, transport it and prepare it to be used in the sugarcane mill.

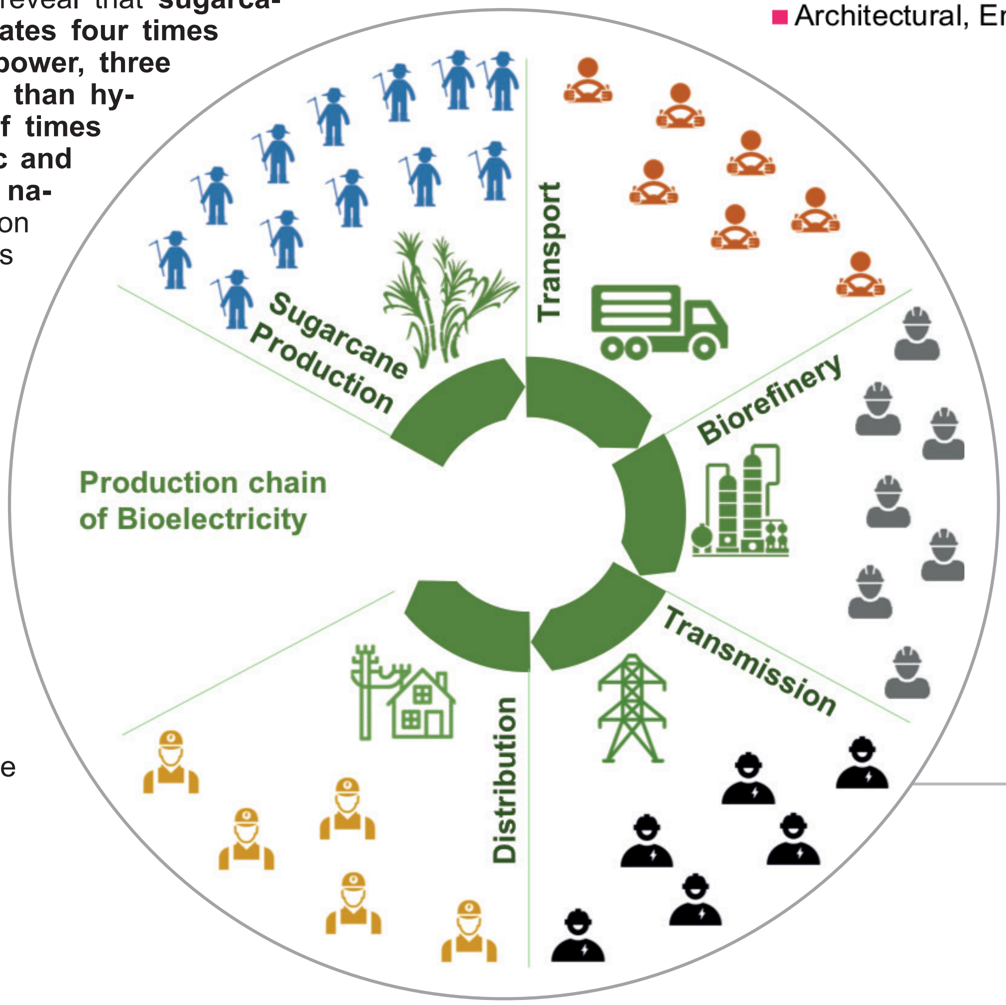
SUCRE Project's results of the social effects account for the **entire production chain**.

For every 1 GWh of bioelectricity generated from sugarcane biomass, 1.47 jobs are created.

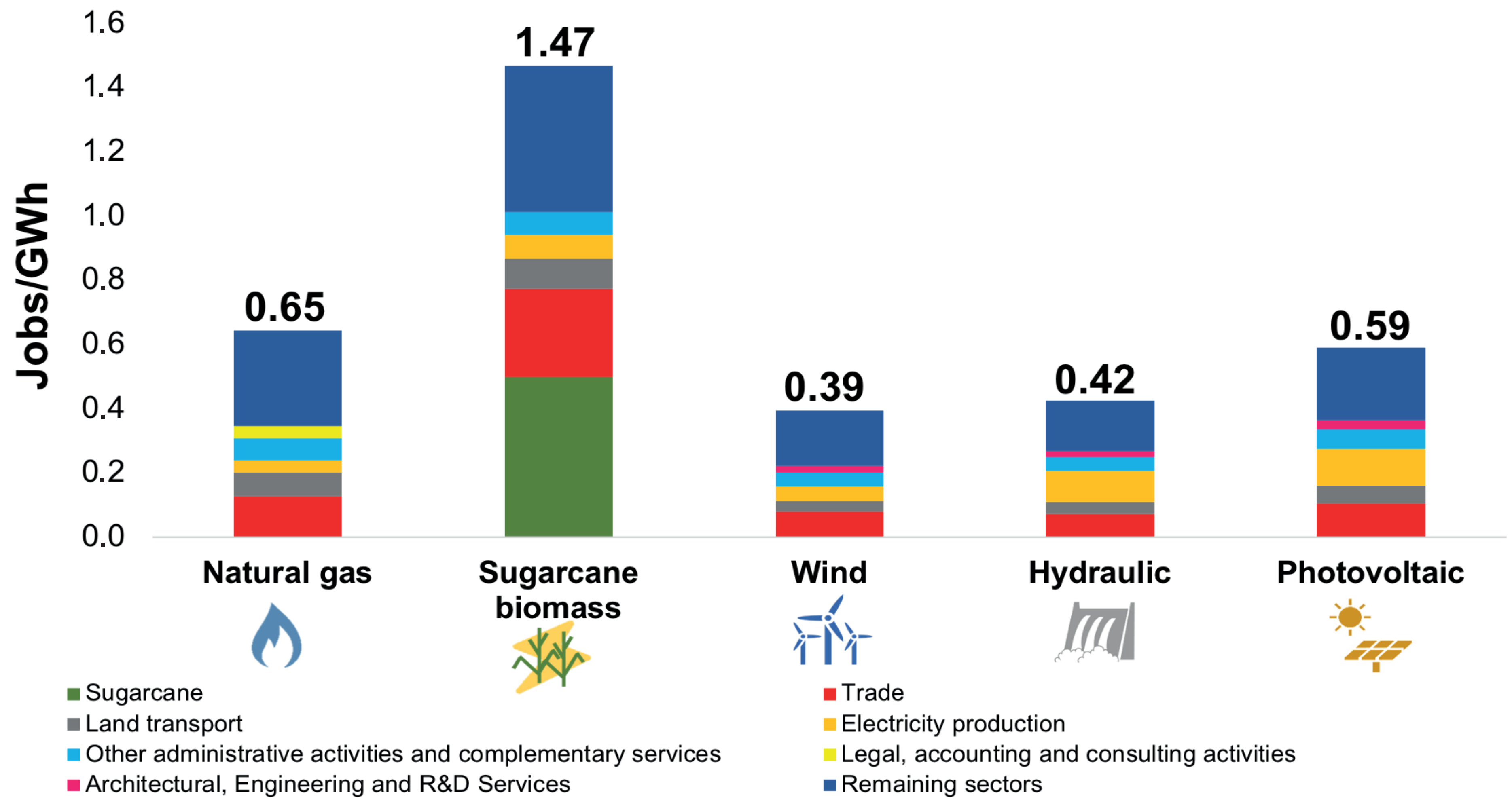
In order to get a better understanding, we can compare the creation of jobs per GWh with other renewable sources, like wind, photovoltaic and hydraulic, and electricity from natural gas, the primary fossil source to be replaced by sugarcane biomass.

Up to now, the results reveal that **sugarcane bioelectricity generates four times more jobs than wind power, three and a half times more than hydraulic, two and a half times more than photovoltaic and two times more than natural gas**. The generation of electricity creates jobs in various sectors of the economy. The majority of the bioelectricity jobs are in sugarcane cultivation and its transportation to the mill.

In photovoltaic generation, most jobs are in the generation of electricity. With respect to electricity from other sources, most of jobs are in the commercial sector and in sectors involving administrative activities.



JOBS GENERATED PER GWh OF ELECTRICITY



Figures for different sources calculated using the Input-Output Analysis, with average amounts for 2015. An optimized electricity generation technology was considered for sugarcane biomass, with an export of 100 kWh/tonne of cane. The jobs only account for the operation and maintenance phase in the generation of different types of electricity

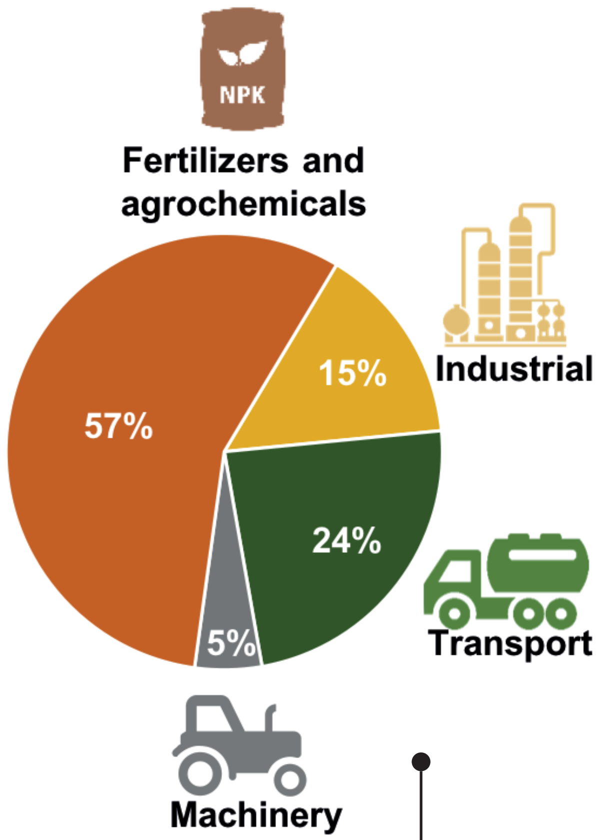
SOCIAL LIFE CYCLE ASSESSMENT

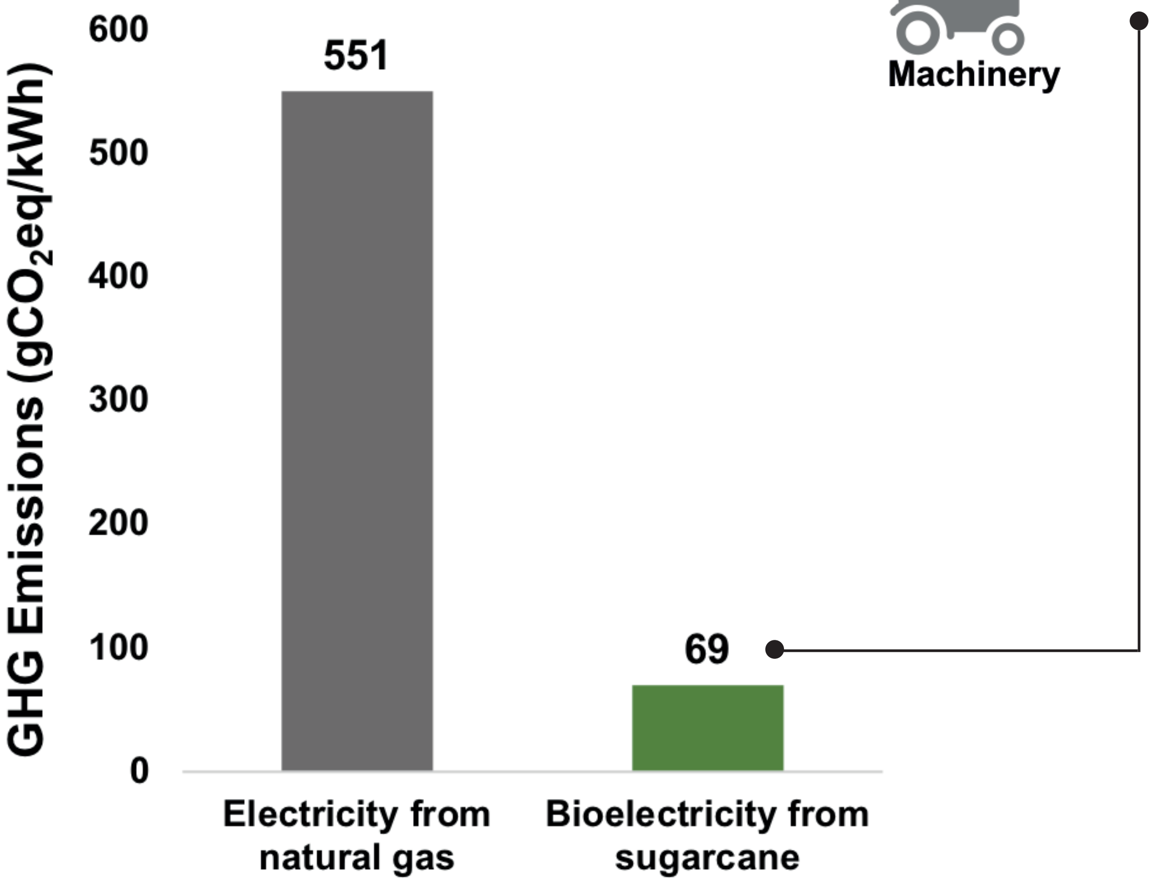
The social analysis also examines the following topics: occupational accidents, average salary for workers, education level of workers and the percentage of men and women.

SUGARCANE BIOELECTRICITY REDUCES GREENHOUSE GAS EMISSIONS

The Life Cycle Assessment (LCA) is used to calculate the greenhouse gas emissions, that can cause global warming and climate change. The LCA considers the **impacts of the entire production chain** – raw materials, fuels and machinery used in the sugarcane production stages, transport, and electricity generation at the sugarcane mill.

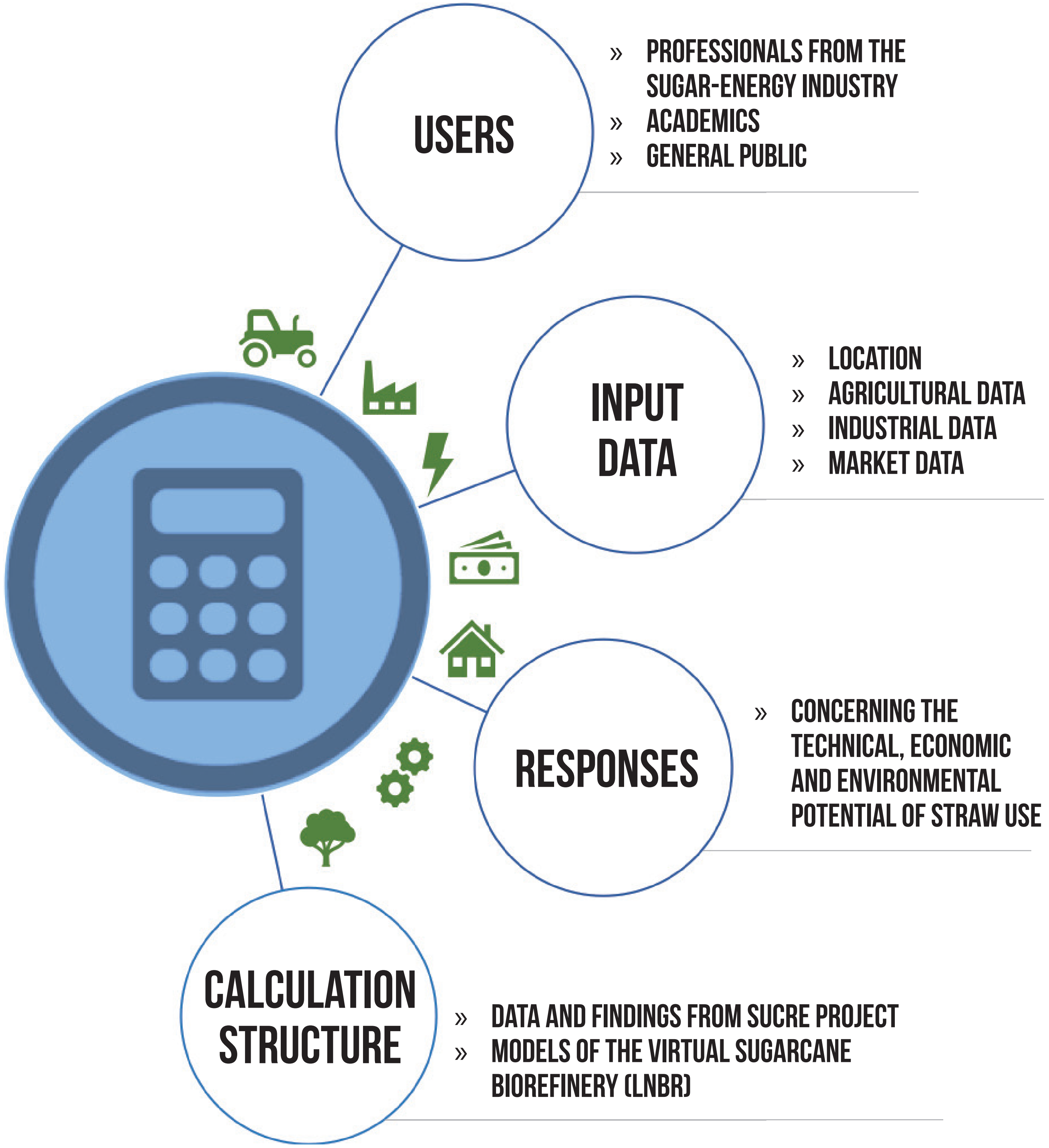
The generation of 1 kWh of electricity from sugarcane emits approximately 69 grams of CO_2 equivalent into the atmosphere. This is much less than electricity from natural gas, which emits approximately 551 grams of equivalent CO_2 per kWh.





CALCULATOR: SUCRE PROJECT'S LEGACY IN A FREE ONLINE TOOL

Drawing on the SUCRE Project's legacy and as a way to share the knowledge created during the Project, SUCRE calculator was developed. Known as the "PalhaCalc" (Straw Calculator, or 'StrawCalc'), it is an easy-to-use online tool that allows preliminary results on the technical, economic and environmental potential related to the recovery and use of straw for the generation of bioelectricity to be created.



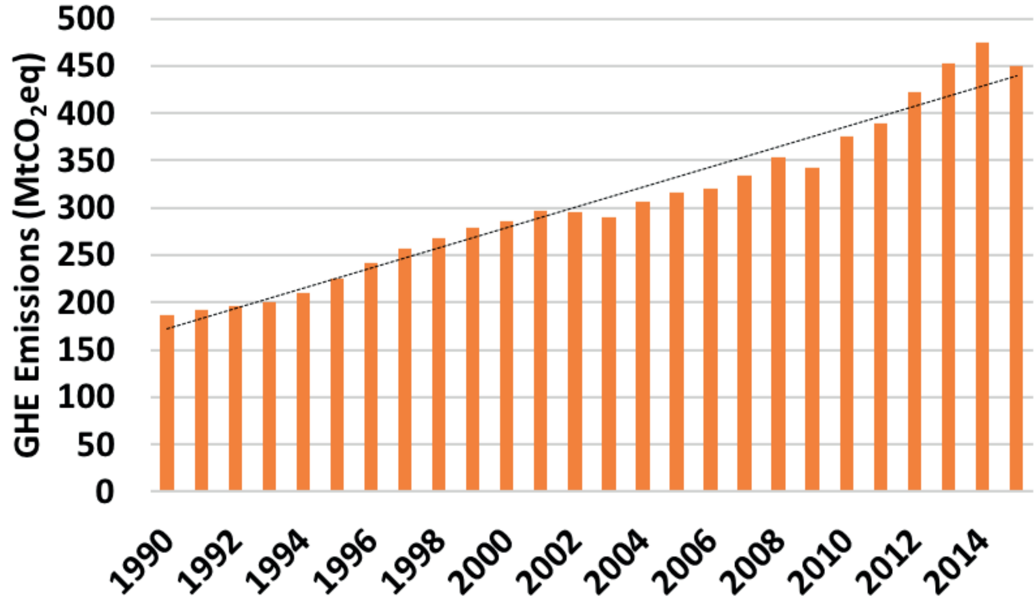
BIOELECTRICITY CAN REPLACE 78% OF RESIDENTIAL DEMAND IN BRAZIL

In addition to calculating the greenhouse gas (GHG) emissions of partner mills, SUCRE Project also evaluated the potential for sugarcane bioelectricity in Brazil to mitigate GHG as compared to natural gas electricity, and the potential to fulfill the country's residential electricity demand.

In 2018, approximately 620 million tonnes of sugarcane were harvested and 21.5 TWh of bioelectricity were exported to the grid, representing roughly 16% of residential electricity consumption. If 50% of straw from all of this harvested sugarcane were recovered, another 42.3 TWh could be exported, totaling 63.8 TWh, which could supply 47.5% of the Brazilian residential electricity demand. Considering the addition of an optimized cogeneration system and an additional 50% of straw harvesting, the potential for sugarcane bioelectricity could reach 104.3 TWh, or 77.7% of residential electricity demand.

THE POTENTIAL FOR MITIGATING GHG

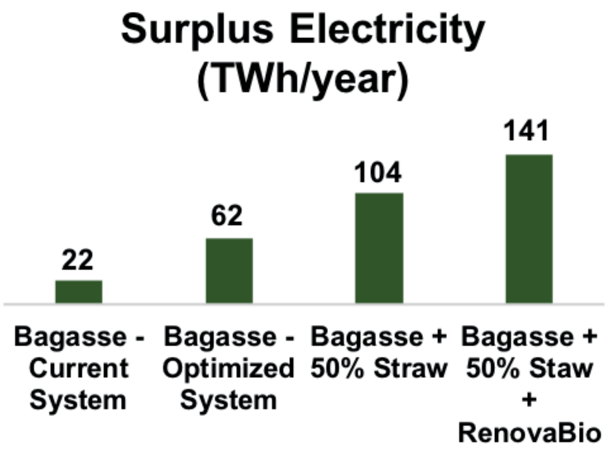
It is extremely important to evaluate the GHG mitigation potential of sugarcane bioelectricity, particularly given the global context of reducing these emissions and the **Sustainable Development Goals (SDGs)**. In addition, emissions from the **Brazilian energy sector increased by 42% from 2005 to 2015**, as shown in the chart below.



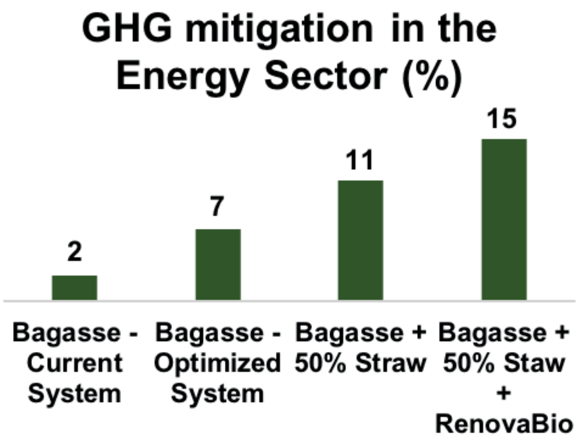
SCENARIOS FOR EXPANDING THE GENERATION OF SUGARCANE BIOELECTRICITY

	Bagasse – Current System	Bagasse – Optimized System	Bagasse + 50% Straw	Bagasse + 50% straw + RenovaBio
Optimized Cogeneration		X	X	X
Straw Recovery			X	X
Area Expansion				X

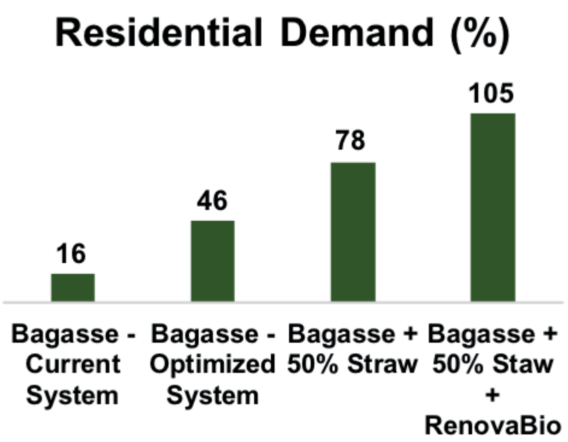
The Bagasse + 50% straw + RenovaBio scenario considers an expansion of 3 million hectares of the sugarcane area to supply/meet the demand of 50 billion liters of ethanol, according to RenovaBio expectations.



Brazil has a tremendous potential for producing bioelectricity from sugarcane. By simply optimizing the existing system, sugar-energy sector could export 62 TWh of bioelectricity per year!



Emissions avoided when replacing electricity from natural gas with sugarcane bioelectricity could mitigate part of the emissions from the Brazilian energy sector, reaching 15% in the Bagasse + 50% Straw + Renovabio scenario.



By recovering 50% of straw from existing sugarcane fields, combined with optimizing the cogeneration system, sugarcane bioelectricity could supply 78% of Brazil's residential electricity demand.

BEYOND BIOELECTRICITY AND THE MITIGATION OF GREENHOUSE GAS EMISSIONS

The focus of SUCRE Project's work on the United Nations Sustainable Development Goals (SDGs) is directly related to Affordable and Clean Energy (**SDG #7**) and Climate Action (**SDG #13**), given that SUCRE attempts to boost the production of electricity with low emissions of greenhouse gases through the use of straw as a compliment to bagasse in boilers being used today. However, the Project's results go well beyond energy and climate change, and indirectly touch on a number of other SDGs.

COMBATING DEFORESTATION

A report by SUCRE's team revealed that 96% of the most recent expansion of sugarcane (over 4 million hectares) took place within the Agroecological Zoning of Sugarcane (ZAE), meaning that sugarcane has expanded over other crops and pasture areas and has not played a direct role in deforestation. Another study reveals that, even being very conservative environmentally, there are still over 20 million hectares available for sugarcane expansion within the ZAE, considering only the six states that most produce cane in the South-Central region of Brazil (Sao Paulo, Goias, Mato Grosso, Mato Grosso do Sul, Minas Gerais and Parana).

WATER AVAILABILITY

Studies published in international scientific journals have also pointed out that the expansion of sugarcane over pastures and annual crops benefits the availability of water in river basins during the dry season.

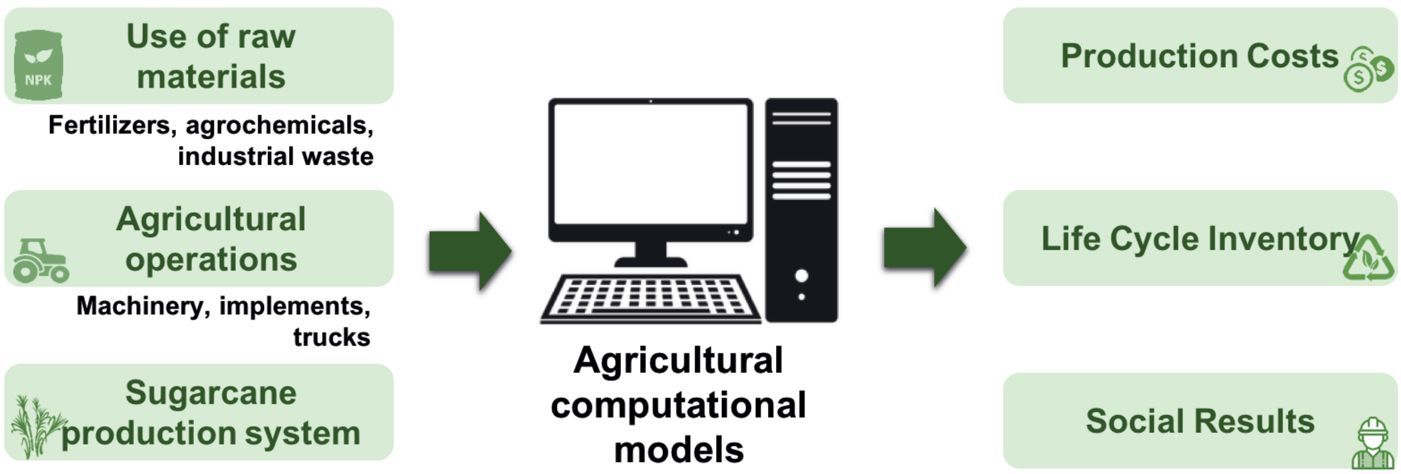
POSITIVE SOCIO-ECONOMIC IMPACTS

The staff from the Project has also worked to address socioeconomic impacts from biomass-based electricity compared to natural gas. Preliminary results suggest that it is possible to create 817 more jobs for every 1 TWh of electricity generated using sugarcane biomass than if that amount of electricity was generated using natural gas. Studies on the diversification of schooling, income and participation by gender are also being conducted under the scope of SUCRE.

METHODOLOGY

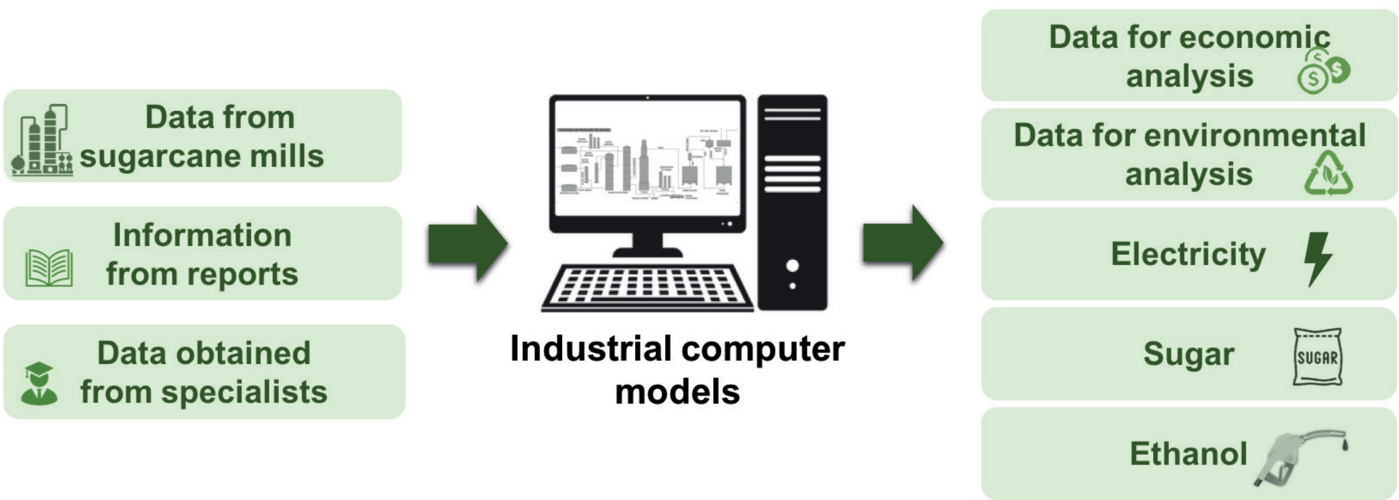
AGRICULTURAL ASSESSMENT

To evaluate the cost of harvesting straw, VSB uses CanaSoft, a tool designed by the LNBR/CNPEM team. It is a computational model that encompasses all agricultural operations of sugarcane production, from the systematization of the area, preparation of the soil, and including the transportation of straw and procedures for recovering straw, while accounting for labor, required machinery and tools, as well as raw materials used. The CanaSoft agricultural model allows technologies that are in use and under development to be assessed, making it possible to identify critical points and technological bottlenecks in the process. Through the use of CanaSoft, we are able to determine points that merit particular attention in agricultural operations based on characteristics of each sugarcane mill examined. This is done to gain better technical, economic and environmental results on the use of straw. In order to determine the cost of straw, CanaSoft calculates the cost difference between the scenario with recovery and a situation without recovery.



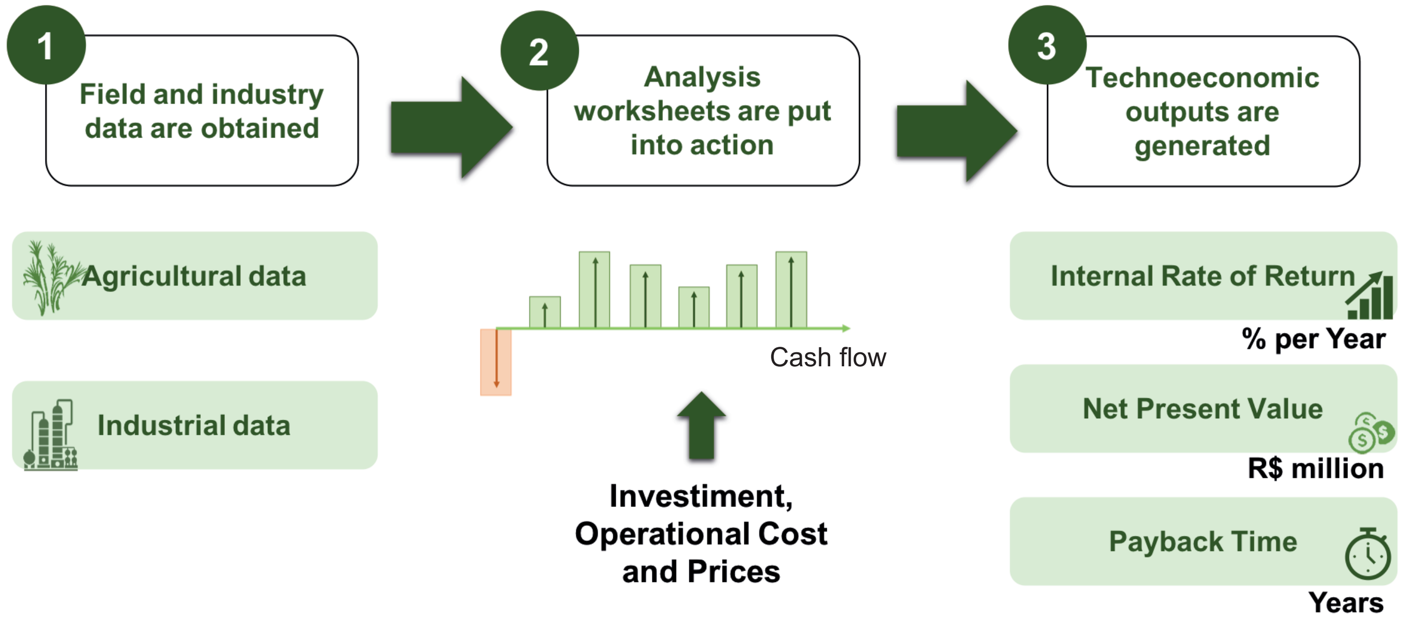
INDUSTRIAL ASSESSMENT

To assess the potential for generating electric power by the mills, computer simulations need to be built that represent the operations for processing and burning straw. The excess electricity generated by the sugarcane mills can be increased by burning straw in the boilers. Using operation and equipment data from the sugarcane mill that are participating in the Project, information from the sector and from published studies, and accounting for factors such as the amount of straw collected and moisture levels, the industrial simulation is designed to generate results that will be used for environmental and economic analysis.



TECHNOECONOMIC ASSESSMENT

After running agricultural and industrial simulations, the next step is to assess whether the generation of bioelectricity from straw will be economically viable for partner sugarcane mills. This analysis is divided into three stages. The first involves using information from the sugarcane mill that was previously delivered to the agricultural and industrial simulation teams. In this stage, essential information includes the electricity prices, since all future revenue will depend on this amount. The second step requires a cash flow analysis to be conducted, which includes investments in equipment and infrastructure, in addition to other costs for factors like labor, industrial inputs and maintenance. In the third and final stage, the responses that will reveal whether the decision was acceptable in economic terms are presented.



SOCIAL ASSESSMENT

In SUCRE Project, the social effects of producing sugarcane bioelectricity are calculated using the Social Life Cycle Assessment (S-LCA) methodology. S-LCA examines the positive and negative social effects at all stages of the production chain. This assures that, for example, workers from the entire production chain are included, and not only the sugarcane mill. People involved in the production of sugarcane, in the production of all materials and services used, as well as workers involved in the transport and trade of all goods and services in the production chain, are all accounted for.

ENVIRONMENTAL ASSESSMENT

In SUCRE Project, the environmental impacts of sugarcane bioelectricity production are calculated using the Life Cycle Assessment (LCA) methodology. This methodology accounts for the impacts of the entire production chain. In other words, raw materials, fuels and machinery used in the sugarcane production stages, transportation, and electricity generation at the sugarcane mill.

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