Improving Greenhouse Gases Market-Based Mitigation Programs: A Case Study of Renovabio – the Brazilian Renewable Fuels Program

Improving Greenhouse Gases Market-Based Mitigation Programs: A Case Study of Renovabio – the Brazilian Renewable Fuels Program

Felipe Jane Bottini

A Thesis in the Field of Sustainability

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

May 2022

Abstract

The use of economic instruments aimed at mitigating the emission of greenhouse gases is gaining ground globally. Brazil's first experience of a domestic regulated carbon market - Renovabio - the Brazilian Renewable Fuels Program, is a case in point. Operating since mid-2020, the Program generates decarbonization credits (CBIOS) that stimulate fuel distributors to shift to biofuels. However, the presence of design and operational flaws in Renovabio is evident. Limited resources and experience in the design of this type of market instrument pose challenges to the Program's environmental integrity and credibility.

To address this problem, I developed a methodological framework that identifies design flaws cost-effectively and transparently, focusing on these questions: Is there empirical evidence of design flaws in the implementation of the Renovabio Program? If so, is the evidence supported by a qualitative assessment? I hypothesized that one or more design/execution flaws could be present in the certification process of the Renovabio Program. This hypothesis stems from the perception that the output of the certification process could be systematically overestimated in some circumstances.

I proceeded in four steps. First, I put together a novel dataset on the certification of 247 companies between 2019 and 2021. Second, I used simple correlation analysis to look for statistical anomalies in the data (correlations that, by premise, should not exist). Third, I consulted with Renovabio experts to validate the legitimacy of the non-association premises and obtained results. Fourth, I made an in-depth analysis of the

regulation and proposed adjustments; I also proposed a framework to look for design flaws in the Program.

The results suggest possible breaches of the environmental integrity in the Renovabio Program that urgently requires solutions. The analysis confirmed the hypothesis for four out of the six associations tested. First, an association was found that suggests a lack of independence of one Verification Body in its assessment of a company's emissions outcomes. A second pointed to a benefit for sugarcane ethanol producers as compared to producers of soy-based biofuels. A third indicated inadequate auditing practices leading to the possibility of an underreporting of diesel consumption, which could inflate the result of the certification process. Finally, a fourth association indicated a design flaw that can lead to certification applicants gaming the system to obtain favorable outcomes.

Finally, I developed a generalized framework that allows program managers to apply simple statistical techniques to assess the environmental reliability of market-based environmental programs.

Author's Biographical Sketch

I hold a bachelor's degree in Economic Sciences from Universidade de São Paulo and a graduate-level title in Environmental Policy and International Development from Harvard University. The last 16 years of my career have been dedicated to projects linked to the ESG agenda, focusing mainly on programs dealing with greenhouse gases emissions and mitigation. I am a founding partner of Green Domus Desenvolvimento Sustentável Ltda, the first Verification Body authorized by The National Oil, Gas and Biofuels Agency to conduct validation and certification audits on biofuel production plants under the Renovabio Program. My involvement in the Program predates its coming into force. I became involved in technical and political discussions on the topic in 2016. The program was passed into law in December 2017. Throughout 2018, regulation was being developed and Green Domus was authorized as VB in January 2019. On October 17th, 2019 we became the first company to finalize a certification cycle under the program. Green Domus was also responsible for the first certification of sugarcane ethanol, corn ethanol, and biomethane producer. Over the last few years, through extensive involvement and participation in certifying over 110 plants, I know the regulation in great detail and am familiar with the program's practical challenges. This has given me the confidence to produce this thesis, aiming to contribute to the qualitative advance of the program and, if possible, inspire similar programs. To contact me, please email felipe@greendomus.com.br or find me on LinkedIn: https://www.linkedin.com/in/felipe-bottini-30a0315/.

Dedication

I dedicate this work to the ones that have supported me not only in this important journey to accomplish a meaningful academic and career milestone, but in several aspects of my life personal life. In special recognition to my wife Ana Beatriz, my daughter Maitê, my parents Nino and Montse, Raymond and Diane (yes, I do have four parents), my brothers Pierpaolo, Zachery, Christopher and Jamie and their wives and children, and my 100-year-old Grandmother Maria Esperanza.

I also dedicate it to some very special people that left this world sooner than expected and hopefully are in a better place, and whose lessons and memories will live forever in my heart and soul: Eliana Fragano Bottini, Guilhermo Fau Cornago, Miguel Lourenço Bottini and Claudia Maia.

Acknowledgments

This entire work was motivated by my personal experience in the Renovabio Program. The conclusions and recommendations are truly what I believe to be the result of an academic scientific procedure and its implementation could result in advantages to all those involved with the Program and concerned about its quality, including myself, my customers and my Company. Thus, if someone thinks there could be a conflict of interest arising from this work, I won´t dispute that. However, my deep involvement with the program allowed me to dive deep into its issues and come up with recommendations to be at least considered.

I want to express my gratitude to ANP representatives that has always been supportive with my questions and claims with regards to Renovabio. I also want to express my gratitude to Ronaldo de Andrade and Rogerio de Andrade for helping me with in uncountable events, from English writing to campus logistics, especially the two-wheeled vehicle.

No words can express how grateful I am to have Petterson Vale as my thesis director. I also want to thank all the stakeholders that provided valuable insights, namely the ones who engaged with the questionnaire and authorized their names to be mentioned in this thesis: Aurelio Amaral, Carlos Xavier, Cauby P. F. Filho, José C. P. de Melo, Leonardo Costa, Leonardo Zilio, Miguel A. S. Vedana, and Ricardo Esparta.

Finally, I thank all Harvard staff, particularly Lacey Klingensmith, Trudi Pires, Professor Mark Leighton, and Professor Richard Wetzler. You are the best!

Table of Contents

Between is capitalized in titles because it is >3 letters

List of Tables

List of Figures

List of Acronyms

ANP	Agência Nacional de Petróleo, Gás e Biocombustível [National Oil, Gas, and Biofuel Agency]
CBIO	Carbon Credit/Decarbonizing Credit: One CBIO represents one metric ton of GHG emissions avoidance
CAR	Rural environmental registration system
CEF	CBIOs Emission Factor: CEF multiplied by biofuel produced in liters provides the amount of CBIOs
E%	Production eligibility factor
GHG	Greenhouse gas(es)
IPCC	Intergovernmental Panel on Climate Change
LCA	Lifecycle Assessment
LCFS	Low Carbon Fuel Standard
MRV	Measurement, reporting, and verification
NEEA	Energetic Environmental Performance Grade, measured in grams of carbon dioxide equivalent emissions avoided per megajoule (gCO2e/MJ).
NDC	Nationally Determined Commitment
PMR	Partnership for Market Readiness
REN	Renovabio Program – “Brazilian Renewable Fuel Program”
UNFCCC	United Nations Framework on Climate Change
VB	Verification Body

Chapter I

Introduction

Carbon pricing, which consists of attributing direct costs to greenhouse gas (GHG) emitters, has been a central element in the use of economic incentives to combat climate change (Kosnik, 2018). One of the tools for carbon pricing is the cap-and-trade market mechanism. An emissions cap is set for economic agents: the agent below the cap generates carbon credits and the one above purchases these credits to offset their excessive emissions. On average, the cap must be observed for the mitigation goal to be met.

Renovabio – REN, the Brazilian National Biofuel Policy, has operated as a cap-and-trade market system since mid-2020. It is the first regulated domestic carbon market in Brazil. As straightforward as the cap-and-trade idea is, there are fundamental implementation challenges for the Renovabio Program's credibility and consolidation as a mitigation policy instrument.

How can one know if emissions reporting is adequate and free from design flaws? Is there is a way to systematically identify, through publicly available data, relevant risks, flaws, or improvement areas regarding the cap-and-trade regulations? One approach to make this possible is to implement an in-depth, data-driven study of the scheme's certification process. For that, it is necessary to understand the type of inputs used for the entire certification process and classify them into data categories based on their potential to reveal substantial environmental integrity risks.

A CBIO is a decarbonization credit that corresponds to one ton of avoided CO2e emissions. Two key measures that are used in the CBIO certification process can be used to assess potential flaws in the scheme. They consist of the calculator inputs that determine the Environmental Energy Efficiency Grade (NEEA), and others that determine the eligibility fraction (E%).

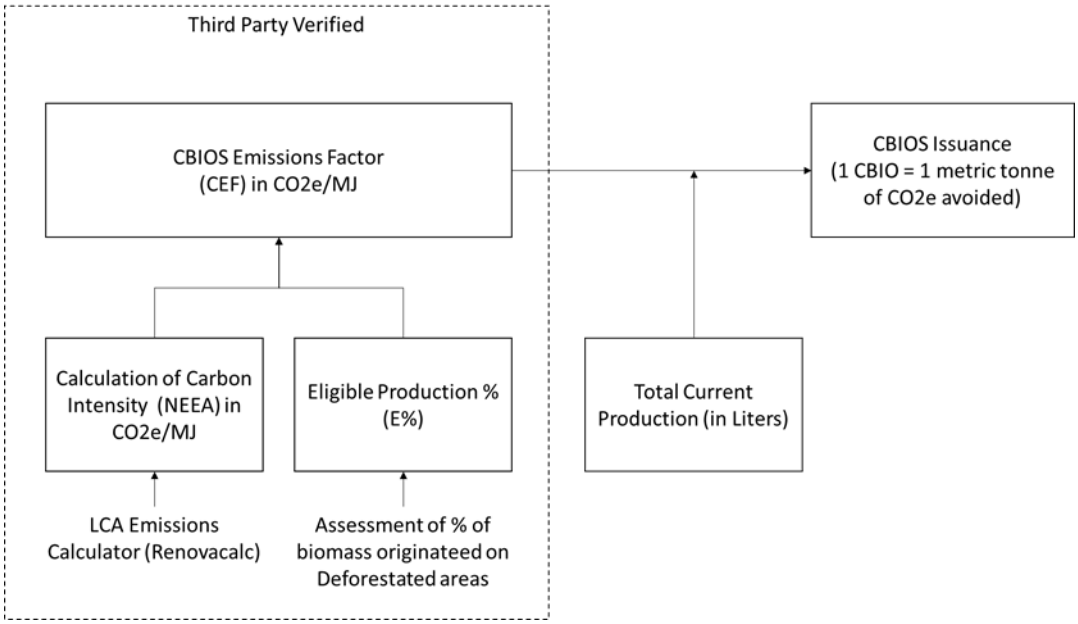

Figure 1. How variables are combined to generate a CBIO.

Differences in these calculator inputs from one producer to another directly and proportionally impact their certification results. For instance, the more fossil fuel used in a producer's agricultural or industrial processes per unit of biofuel produced, the less GHG-efficient he/she is. Ensuring the integrity of these inputs can be done using well-known auditing practices as required by ISO 19.011, one of the requirements for Renovabio Program verification services providers (Ministério de Minas e Energia & National Oil Agency, 2018).

However, factors that are not firm-specific should not affect the carbon intensity certification results. This is a standard premise underpinning any certification process. For instance, the choice of one third party verification body (VB) (which is not firm-specific) over the other should not generate better or worse results in the CEF for a biofuel producer. Accordingly, the difference found in the deforestation rates of feedstock providers should not be affected by the type of biofuel produced, but by actual deforestation in that area.

Any influence of these non-firm-specific factors on certification outcomes poses risk to the program integrity. A deep analysis of the relationship between non-firm-specific factors and certification outcomes can reveal essential risk areas in the program, which requires improvement of rules and practices to avoid relevant flaws to impact the policy as a whole. Indeed, an initial assessment of a novel program dataset was a useful technique to identify potential flaws in the process and recommend improvements. A better understanding of those factors and their impact on the Renovabio Program's integrity is urgently needed since significant legal disputes are happening and could threaten the program (Gaudarde, 2020).

Research Significance & Objectives

This research focused on identifying potential design flaws in the certification process under the Renovabio Program. For this purpose, I used exploratory statistical analysis along with Program experts who answered a questionnaire to identify factors affecting certification outcomes that should not, by premise, be affecting them. By using a novel dataset along with key stakeholders' interviews to assess the program, this

research contributed important implications for policy design in Renovabio Program and other similar programs elsewhere.

The data analysis identified gaps otherwise difficult to detect. Results were used to design proposals for regulation adjustments, including a new quality check approach, and metrics to evaluate regulations enforcement for integrity. This type of analysis was aimed to support a systematic agenda for improvement in the Program and inspire other GHG mitigation cap-and-trade systems yet to be developed in Brazil and abroad.

Therefore, the primary research objectives of this study were to:

- Use a rigorous approach to identify and justify the choice of several pairs of variables that should not be associated with the certification outcomes, and test if those variables behave as expected or not.
- Analyze plausible explanations for the unexpected associations of those variables with certification outcomes.
- Propose technical regulation adjustments for policymakers to support program integrity improvements, addressing anomalies where they shouldn't appear.

Background

Climate change is not only the greatest threat humankind has ever faced but also a challenge where insufficient advances have been made. GHG emissions are still on the rise. If the average global temperature grows over 2º Celsius since the industrial revolution, outcomes are likely to be unmanageable (Myhre, 2013). The international policy scenario shows that current pledges for mitigation will likely lead global GHG emissions to some 59GtCO2e in 2030 (UNFCCC, 2010). UNEP's proposed target to

avoid a temperature rise above two degrees, compared to pre-industrial average temperature is 40Gt for 2030 (Olhoff, 2018), indicating that countries need to implement much greater reductions in GHG emissions.

An earlier wave of climate economy impact studies pointed out that losses resulting from inaction will count from 5-20% of global GDP yearly, while mitigating those emissions and associated losses acting for mitigation would require about 1% of yearly GDP investment worldwide (Nordhaus, 2007; Stern, 2008; Mityakov, 2009). More recent studies predict that a 2.5-3.0 degrees temperature increase above pre-industrial levels would result in a 15-25% reduction in per-capita economic outputs. If temperature increase is kept between 1.5 and 2.0 degrees, there is a "60% chance that the accumulated global benefits will exceed US$20 trillion under a 3% discount rate" (Burke et al., 2018). Although climate change mitigation is urgent, technologically doable, and economically feasible, little has happened in the past two decades, mostly because advocacy efforts proved insufficient to motivate action. A different approach, incentive-driven, is needed (Liverani, 2009).

Under such dramatic circumstances, policies that create economic-driven incentives, especially for liquid fuels, have gained attention and are promising. For a decade, some have been in place, such as the low carbon fuel standard (LCFS) program in California (California Air Resources Board, 2010), while others are just starting, such as Renovabio in Brazil (República do Brasil, 2017). The mechanics behind these policies are to hold the issuer accountable economically to incentivize emissions avoidance (Kosnik, 2018).

Carbon Pricing Options and Brazil's Choices

There are countless alternatives for carbon pricing mechanisms. The best-documented ones are carbon taxing and cap-and-trade. More than 800 carbon pricing systems under one of those alternatives were implemented worldwide by 2015 (Interamerican Development Bank, 2016; Chassagneux, 2017).

Carbon taxing intends to both incentivize issuers to avoid emissions and to use resulting tax income to promote climate change mitigation and adaptation actions (Interamerican Development Bank, 2016). One main issue arising from a carbon tax is that it tends to be regressive, negatively affecting low-income families while benefiting richer ones (Interamerican Development Bank, 2016), thereby increasing income inequality. According to the World Bank GINI Index (World Bank, 2021a), Brazil ranked last among 29 developing countries in wealth and income inequality in 2018 (World Bank, 2021b); implementing a carbon tax instrument in the current context seems inappropriate to tackle emissions in Brazil.

The World Bank Global Initiative, Project Market Readiness (PMR), supported a long-term study to identify and advocate for Brazil's best available carbon pricing strategy. Its implementation status report concluded that carbon pricing through market-based solutions is cost-effective and being adopted by several OECD Countries as it is the best practice for carbon pricing (World Bank, 2019a). These conclusions directed Brazil's efforts to focus on developing a cap-and-trade regulation, although it has to be recognized that regressivity could also occur in a market-based solution.

Motivated by Brazil's Nationally Determined Commitment (NDC) under the Paris Agreement (United Nations, 2015), in which Brazil has committed to reducing its

absolute emissions by 37% by 2025 (República do Brasil, 2015), the National Biofuel Policy, also known as Renovabio (REN), was established in 2017 (República do Brasil, 2017). The Renovabio Program determines the rules and procedures for generating, acquiring and retiring decarbonization credits (CBIOs) to reduce the GHG emission intensity of liquid fuel consumption through a cap-and-trade system. Its implementation resulted in the setting up of the first Brazilian carbon market. Starting in December 2017 by law enforcement, the first CBIOs transaction occurred on June 15, 2020 (B3, 2020).

Renovabio Market Mechanics and Decarbonization Targets

On the demand side are the fuel distributors that are obliged to buy CBIOs for emission offsetting purposes. The distributors must purchase an amount of CBIOs sufficient to cope with their annual mitigation targets. Each distributor's purchase target is calculated based on its share of fossil fuel energy sold in the domestic market. Distributors must buy and retire their allocated target of CBIOs yearly, with a 15% carryover flexibility allowed by Article 7 § 4 of Renovabio (República do Brasil, 2017).

Table 1. Yearly Renovabio mitigation targets in million from 2020 to 2030.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CBIOS (Ton of CO2e avoided emissions)	14.53	24.86	34.17	42.35	50.81	58.91	66.49	72.93	79.29	85.51	90.67

Source: Departamento de Biocombustíveis/SPG/MME, 2020

Renovabio' s objective is to reduce GHG emission intensity of nationally burnt liquid fuels by 11.4 % in one decade, moving from 73.57 gCO2e/MJ in 2020 to 66.04

gCO2e/MJ in 2030 (Departamento de Biocombustíveis/SPG/MME, 2020). One CBIO is equivalent to one metric ton of avoided GHG emissions.

How Biofuel Producer Gains are determined under Renovabio

A producer calculates and certifies its biofuel lifecycle emissions in terms of CO2e/MJ. The certificate states the difference between the producer carbon intensity against its fossil fuel alternative carbon intensity baseline, given by the RENOVACALC. This difference is named the Environmental Energy Efficiency Grade (NEEA). The NEEA weighted by the production eligibility fraction (E%) results in the CBIOs Emission Factor (CEF). Accordingly, the CEF multiplied by biofuel actual production generates the decarbonization credits, or CBIOs (Figure 1).

By the end of 2020, 237 biofuel producers were certified. JBS S.A. – Lins SP, at the higher CEF end of the program, generates one CBIO for every 408.6 liters produced and sold. Usina Petribu SA, on the other end of the CEF range, has to produce 2,224,29 liters to generate one CBIO (National Oil, Gas and Biofuel Agency, 2020a). Such enormous differences hint at how relevant CEF is for a biofuel producer to gain revenue from CBIOs sales. It is therefore in the producers' interest to know in detail the variables that compose the CEF and improve them whenever possible, namely the E% and the NEEA.

NEEA – Environmental Energy Efficiency Grade

NEEA is obtained from the program's calculator, RENOVACALC (National Oil, Gas and Biofuel Agency, 2020f; National Oil, Gas and Biofuel Agency, 2020g). RENOVACALC is in its version 6.1 and was developed by a lifecycle assessment

specialists' academic team from the Brazilian Agricultural Research Corporation (EMBRAPA) under certain methodological options and premises (Ministério de Minas e Energia & National Oil Agency, 2018) (Table 2).

RENOVACALC use is mandatory and the only option to calculate the NEEA. There is a different tool for each production route: 1st Generation Sugarcane Ethanol and Biodiesel are the most frequent ones, counting for 220 out of 237 certificates (National Oil, Gas and Biofuel Agency, 2020a). The RENOVACALC was built as a lifecycle emissions intensity calculator and includes the agricultural, industrial, and distribution phases with its related GHG emission sources (National Oil, Gas and Biofuel Agency, 2020e).

Table 2. Renovacalc methodological options and premises.

Approach	Atributional
Scope	Cradle to Grave
Functional Unit	Burnt Fuel in MJ
Byproducts emissions allocation	Energy based
Data-source for emission factors	ecoinvent v.3.1 - Priority was given to the adoption of production and processing inventories for Brazil (BR), global (GLO2) and, when these were unavailable, the 'RoW3' inventories were used.

A biofuel producer must report agricultural and industrial production, and distribution data, and hire an authorized third-party verification body (VB) to assure RENOVACALC inputs and eligibility fraction. The calculator inputs feed equations that automatically calculate the NEEA. Specific inputs may differ from one producer to another, which will cause each of them to have a specific NEEA and related CEF. There

is a direct relationship between entry data, NEEA and CEF, which will reflect the issuance of more or less CBIOS for a certain amount of biofuel production (Figure 1).

Regulation Gaps in the Renovabio Program

Such a novel program like Renovabio that relies on accountable emission reductions needs a regulatory apparatus unavailable until its establishment. However, the first set of implementation rules and procedures are limited and in need of improvement. Concerns are arising on this issue as the program reaches its maturity stage (National Oil, Gas and Biofuel Agency, 2020c; National Oil, Gas and Biofuel Agency, 2020i). A systematic approach to reviewing those rules and procedures based on a scientific method is not in place, so policy improvements are a result of subjective adjustments.

Indeed, the verification process is complex and frequently subject to misunderstandings between fuel producers, certification bodies, and the regulating agency, motivating frequent rules and procedures updates: by the end of 2020, verification guidance was in its fourth version and calculator on its sixth (National Oil, Gas and Biofuel Agency, 2020c; National Oil, Gas and Biofuel Agency, 2020d). The rules changes are based on the perception of its importance by the regulator.

It is essential to acknowledge stakeholders' strong commitment and dedication to the program, including personnel from its governing agency, the National Oil, Gas and Biofuel Agency. However, the best effort review of rules and procedures might cause relevant technical risks not to be perceived if solely through regulation optics, and thus not addressed.

A program like Renovabio, designed to last for ten years (República do Brasil, 2017), requires an ongoing structured review process driven by objective, identifiable

relevant discrepancies. Developing a framework that allows finding and evaluating those discrepancies, testing for anomalies, and using it to improve the Program is a good starting point to overcome critical gaps.

Research Questions, Hypotheses, and Specific Aims

The research questions I addressed were: Is there empirical quantifiable evidence of design flaws in the implementation of the Renovabio Program? If so, is the evidence supported by a qualitative assessment?

I hypothesized that one or more design/execution flaws would be present in the certification process of the Renovabio Program. This hypothesis stemmed from the perception that the NEEA estimate, which is an output of the certification process, could be systematically overestimated in some circumstances.

Below are the non-firm-specific factors that I hypothesized to be affecting certification outcomes:

- H1: The choice of VB affects the NEEA. This hypothesis indicates that the outcome of the certification is linked to the VB chosen and not simply to the specific details of the certified entity, breaching the requirement for the assessment to be independent and replicable. In the context of independent analysis, the choice of one VB over another should not create advantages or disadvantages in certification outcomes.
- H2: The type of biofuel under certification affects the eligibility fraction. This hypothesis indicates that the biomass used to produce biofuel has differing levels of eligibility, not solely as a result of originating from a non-deforested area but

also as a result of the type, or route, of the biofuel produced from it. The eligibility parameter should be determined solely on the conditions of biomass origination.

- H3: The choice of VB affects the proportion of nitrate fertilizer reported on the calculator option “Other” and subsequent NEEA. This hypothesis indicates that better or worse outcomes depend on the point at which the information about nitrate fertilizer is entered into the calculator. This should not occur if the evaluation and acceptance of this type of information were homogeneous across VBs, which is desirable to avoid compatible operations being certified at different levels of efficiency.
- H4: The time at which a plant entered the Program determines the average certification timeline. This hypothesis predicts that the earlier the plant entered the program, the greater the average time to obtain the certification. As the program evolves, it is desirable that there is a learning curve and that certification timelines are reduced.
- H5: The choice of VB affects the average certification timeline. This hypothesis predicts that average certification timelines are affected not only as a result of the information analyzed but also by the choice of VB. If a VB is systematically quicker or slower, we need to understand which elements lead to this and whether or not they are legitimate.
- H6: The choice of VB affects the quantity of fuel reported in the production and harvesting of sugarcane. This hypothesis indicates that using more or less fuel is

not solely associated with operating conditions in the field, which cannot be justified.

Preliminary research I conducted with regards to H1 above revealed that of the three most active verification bodies, with more than 93% of combined market-share in 2020 (National Oil, Gas and Biofuel Agency, 2020a), one seems to systematically provide better NEEA certification for sugarcane producers than the other (Bottini, unpublished data).

Regarding H2 above, my early analysis detected that biodiesel production routes have no more than 39% of eligible agricultural feedstocks, accounting for an overall eligibility of 45%, while the sugarcane ethanol route accounts for 89%. Unless there is a strong reason to accept that deforestation practices are twice as large in soybean farms as in sugarcane ones, which does not seem to fit the facts, there might be some relevant flaw in the ruling that promotes such disparity. This difference implies that biodiesel producers can generate less than half of the CBIOS than a sugarcane ethanol producer for the same amount of energy delivered through its biofuels.

Based on this preliminary evidence, the above variables were hypothesized (H1 to H6) to be associated with certification outcomes, although – by premise – they should not, indicating a rationale why they must be examined in this research.

Specific Aims

To complete this research, the following steps were taken:

1. Collect and organize publicly available RENOVACALCs used for biodiesel and sugarcane ethanol plants certification from the beginning of the Program in 2019

to the end of April 2021, along with other qualitative information of the certification process, into a single dataset (Bottini, unpublished data).

2. Statistically test for associations among variables that should not be associated by premise.
3. Qualitatively assess associations that could generate an observable bias on the result by interviewing relevant stakeholders to gather their perceptions over the specific findings.
4. Develop explanations for each of the associations found, ruling out, or not, the alternative hypothesis that a correlation is justified and not biasing results.
5. Suggest rule and procedural adjustments to improve the program by eliminating unwanted associations between variables.
6. Propose a structured framework to promote a cyclical structured Program quality approach under the same method used to define and test the hypotheses of this dissertation.

Chapter II

Methods

This section presents the methodological procedures used. First, it discusses data collection and handling. Next, it deals with the method for identifying possible advantages of different approaches in data reporting, known as “gaming”. Then, it discusses the pairs of variables that were studied and the appropriate statistical methods applied to test each hypothesis. Finally, it discusses how I obtained qualitative information by engaging experts in the Renovabio Program.

Data Collection and Handling

Certifications carried out by the three Verification Bodies (VBs) with the largest market share were analyzed in this study since they have 96.8% of market share and from which available information suffices for statistical tests and hypothesis testing (Table). Their identities are concealed and referred to as “A”, “B” and “C”. Data are not disclosed at the plant level to ensure the privacy of non-public information.

This dissertation employs both public and non-public data from the Renovabio program. These data were compiled into a dataset for proper classification, use and analysis. Public data were gathered from the ANP website (https://www.gov.br/anp/pt-br/assuntos/renovabio) during each project’s mandatory 30 days period of public consultation, ending on 04/27/2021.

Non-public data were gathered from Green Domus certification processes. Thus, from the meta-data, it is not possible to find or infer specific inputs for individual plants. The spreadsheet is confidential.

Up until 04/27/2021, 247 biofuel production plants had been certified in Brazil under the Renovabio Program (Table): 223 sugarcane ethanol plants, 23 biodiesel plants, and one biomethane plant (National Oil, Gas and Biofuel Agency (2020a). Biomethane was not analyzed here since there is only a single unit, not allowing for any statistical analysis. All certified ethanol and biodiesel producers available in the public system were included in the dataset.

The data set provided this study with a highly representative sample of most of the program data, allowing me to run statistical tests to check for data associations. The primary data were input into the raw-data tab. Other tabs derived from raw data were organized and used for statistical tests and obtaining most of the tables and figures used in this dissertation. Those tabs were: outliers' identification, t-tests (E1GC), t-tests (E1GC) outli, t-tests (E1GC) timeline, t-tests (E%) & (timeline), t-tests (E%) & (timeline) outli, and t-tests (N fertilizers).

Since most of the statistical tests checked for average deviations for pairs of variables in comparison with a control group as a signal of undesired associations, an outlier analysis was also carried out since those could interfere with the average results. The results of these outlier analyses are presented in Appendix 1.

As far as I know, this type or similar dataset has never before been used for an in-depth assessment of the Renovabio Program's technical robustness in a structured way.

The input data from RENOVACALC are all determinants of NEEA, and are not the focus of this study (National Oil, Gas and Biofuel Agency, 2020e). Instead, I looked for non-firm-specific factors affecting certification outcomes that should not, by premise, be affecting the outcomes.

To that end, the investigation adopted a two-pronged procedure: first, I identified variables in the dataset that are empirical representations of the hypothesized factors, and used exploratory statistical analysis to test for associations between the selected variables and the Renovabio Program outcomes. Once a set of empirical associations was found suggesting that some of the Program's outcomes may be systematically biased, these were then used, in a second step, for a qualitative assessment of the Program and to propose, whenever needed, adjustments,

Strategic Data Reporting ("Gaming")

With regards to the inputs of the RENOVACALC as determinants of NEEA, and thus, not focus of this study, there is one exception.

In cases where RENOVACALC allows the insertion of the same variable in different fields, as an option for the firm, it was necessary to know whether the data entry position resulted in different outcomes for better or worst certification results. That is, an association test was done for positional asymmetry, not on the variable itself.

Mr. Ricardo Esparta, since 2009 a member of the United Nations Framework Convention on Climate Change – Clean Development Mechanism Accreditation Panel, informed me that recognizing this possibility for different input positions and deliberately taking advantage of it is of great concern to the Convention and is known as "gaming".

Acknowledging gaming and adjusting program tools to avoid this possibility was an important driver of UNFCCC accreditation and methodology panels for considering acceptance of methods within their framework (R. Esparta, personal communication, September 9, 2021).

In Renovabio Program, information about nitrate fertilizers can be subject to gaming. Since nitrate fertilizers are important sources of N_2O, a powerful greenhouse gas, and preliminary analysis suggest the possibility of gaming that would result in differences in the certification results, it was relevant to this study.

After this procedure, the unassociated pairs of variables were tested to check if an association existed. The t-test was chosen since it provides a way to compare if a variable's mean value is statistically different from a control group. If no statistical difference among the mean values of the sample and the control group exists, the hypothesis of an association with the variable is rejected, and vice-versa.

Proposed Pairs of Variables to Study

After analyzing the dataset, the variables and groups proposed to be tested, in search of statistical associations as representative of the Renovabio Program anomalies, were:

- For H1: VBs "A", "B", and "C" certified NEEAs in g of CO2e/MJ, against Average Certified NEEAs from all other VBs.
- For H2: Average eligibility fraction (E%) obtained by certified biodiesel producers against average eligibility fraction (E%) obtained by certified sugarcane ethanol producers

- For H3: VBs “A”, “B”, and “C” certified proportion of nitrate fertilizers reported on the option “other N” against the certified proportion nitrate fertilizers reported as “other N” from all other VBs.
- For H4: Average certification timeline of the first 35 issued certificates against the average timeline certification of the last 35 issued certificates.
- For H5: Average certification timeline of VBs “A”, “B”, and “C”.
- For H6: VBs “A”, “B”, and “C” certified amount of field diesel per harvested ton against the average certified amount of field diesel per harvested ton from all other VBs.

Statistical Testing: The Student's Unpaired T-test

Student's unpaired t-test is an appropriate statistical technique to check for differences of mean values for variables within different sample sizes under the same population (Glen, 2021). The analysis generates a p-value, formally defined as the probability that the result obtained is spurious, assuming that the null hypothesis is true. A p-value <=.05 is the accepted threshold that the calculated difference between the means is statistically significant and was adopted in this study.

Whenever a t-test that confronted two or more variables with p-values <=.05, an association between those variables indicated a correlation where it shouldn't occur. Whenever it occurred, the unassociated premise was revisited. Only after acquiring sufficient information and awareness of the variable background and possible previously unidentified factors that could cause self-selection or other justification for the association, the acceptance or rejection of the hypothesis was made. Revisiting the

premise was not made as a matter of assessing the premise, but to reinforce the validity of the hypothesis, and that no observable and justified reasoning could legitimize the observed association.

Experts Qualitative Assessment

To acquire sufficient knowledge and make informed propositions, I conducted an in-depth analysis, including sharing a questionnaire with Renovabio experts in the field of regulation, consultancy, and certification. Their opinions were requested for four out of the six formulated hypotheses, the ones for which associations were found. The questionnaire was designed to share results and ask the experts about their acquaintance with the issue, its relevance and risk to the program, and finally its causes and viable solutions.

This approach allowed not only a better understanding of different stakeholders' views but also to check for any inconsistency of the premises. Thus, answers were used to enrich analysis with additional cross-examination for the hypothesis. The structured questionnaire was sent to 21 experts from which 13 engaged (Appendix 2).

Regulation Review

In addition, I reviewed the regulatory literature to assess whether regulation gaps could, to some extent, allow such verified distortions to happen. This desk review considered the law and non-legal instruments that govern the program (Table 3).

Table 3. Regulatory documents reviewed.

ANP Resolution nº 829/2020	Amends Annex II of ANP Resolution No. 802 of December 5, 2019.
ANP Resolution nº 802/2019	Establishes the procedures for generating the necessary ballast for the primary issuance of Decarbonization Credits, referred to in art. 14 of Law No. 13.576, of December 26, 2017, and amends ANP Resolution No. 758, of November 23, 2018.
ANP Resolution nº 758/2018	Regulates the certification of the efficient production or import of biofuels referred to in art. 18 of Law No. 13.576, of December 26, 2017, and the accreditation of verification bodies.
Law #º 13.576/2017	Provides for the National Biofuels Policy (RenovaBio) and other measures.
Technical Note nº 02/SBQ (v.3)	General Guidelines: Procedures for Certification of Efficient Production or Import of Biofuels
Technical Note nº 03/SBQ (v.2)	Guidelines for filling out RenovaCalc
Technical Note nº 04/SBQ (v.2)	General Guidelines - Documentation for the Certification Process for the Efficient Production or Import of Biofuels
D Form	Certificate of efficient production and import of biofuels

I then proposed regulation adjustments to fulfill this study's mandate to improve the GHG market-based mitigation Renovabio Program. In addition, I proposed a framework that could be used by this and other similar programs to explore unexpected data associations for its improvement.

This thesis and related conclusions, including program adjustment recommendations will be sent to the Ministry of Mines and Energy and the National Oil Agency.

Chapter III

Results

This section presents the quantitative analyses results, the experts' responses to the questionnaires, and considerations regarding outliers.

Quantitative Analysis

The quantitative analysis was based on the number of certificates by VB (Table). It shows the contributions of the three verification bodies responsible for the vast majority of all concluded certifications, as well as the number of certifications concentrated in sugarcane ethanol producers. Thus, the analyses focused on where there were sufficient observations to ensure the statistical viability of the analyses comparing VBs "A", "B" and "C", and therefore mostly for sugarcane ethanol.

Table 4. Number of certificates by Verification Body per biofuel type.

Verification Body (VB)	Sugarcane Ethanol	BIODIESEL	Corn Ethanol
A	46	0	0
B	62	19	1
C	119	0	0
Other VBs	7	4	0
Total	223	23	1

In the following tables, p-values marked with an asterisk and underlined are those significantly different from the expected value and from which the difference results in a certification advantage, in other words, bias in relation to what was expected results in a benefit in certification and therefore is the central focus of this dissertation analyses and conclusions.

Data presenting an unfavorable bias are less important as they do not create any benefit for certification and do not pose a risk to the program's environmental integrity. Those were not analyzed in depth.

Certification Timeline, Eligibility, and NEEA Associations

The results of the t-tests for certification timeline, eligibility, and NEEA results of each VB against all others are presented in Table 5. The results showed that variables analyzed were sensitive to the type of biofuel produced. Thus, it was appropriate to conduct a separate analysis for each relevant route: biodiesel and sugarcane ethanol. Complementarily, the biodiesel and corn ethanol routes have only 23 and one certifications, respectively, not qualifying for statistical analysis (Spiegel, 1993). Therefore, the statistical tests were conducted only on the sugarcane ethanol route.

Table 5. T-tests for certification timeline: E% and NEEA against VBs.

Verification Body Certificates	Certification Timeline		Eligibility Fraction		Ethanol (NEEA)	
	Days	p-value	%	p-value	gCO2e/MJ	p-value
A (N=39)	92.3	0.0011*	84.89%	0.0194*	58.4413	0.1252
B (N=64)	121.2	0.0003*	90.01%	0.7546	58.7998	0.1340
C (N=113)	106.0	0.3023	90.58%	0.2591	60.4136	0.0425*
Total (N=223)						

Only sugarcane hydrous ethanol routes were considered. P-values equal to or below 0.05 reveal statistical significance for the average differences where it was not expected.

The results (Table 5) demonstrated that:

- There was a relationship between VB "C" and a better NEEA (H1). VB "C" is the one with the largest presence and the best certification result.
- There is a relationship between the eligibility fraction and VB "A" (H2). However, the relationship does not represent an advantage to VB "A" certifications. Therefore, this indicates that the correlation does not pose a risk to the environmental integrity of the program, therefore it was not discussed in more depth.

There was also an association between the timeline for obtaining certification and VBs (H5). While "A" had the quickest certification cycle, "B" had the slowest (Table 5)

As each VB entered the program at a different point of time, with “A” the most recent, authorized by the regulator since 09/23/2019 and “B” the first among the main players, authorized by the regulator since 01/10/2019, a temporal analysis was conducted to understand whether the difference in the timelines could be influenced by other factors, resulting in a spurious relationship between the VB and the certification timeline.

The evidence indicated that there was no relevant certification timeline difference between the VBs once their Program entry date is considered. The gain from VB “A” occurs because it entered the program at a stage on which the learning curve had led to smaller certification timelines for everyone (Table 14).

Thus, the result does not require the statistical difference to be discussed (Figure 2-5), as it has been explained and relevant differences could not be found.

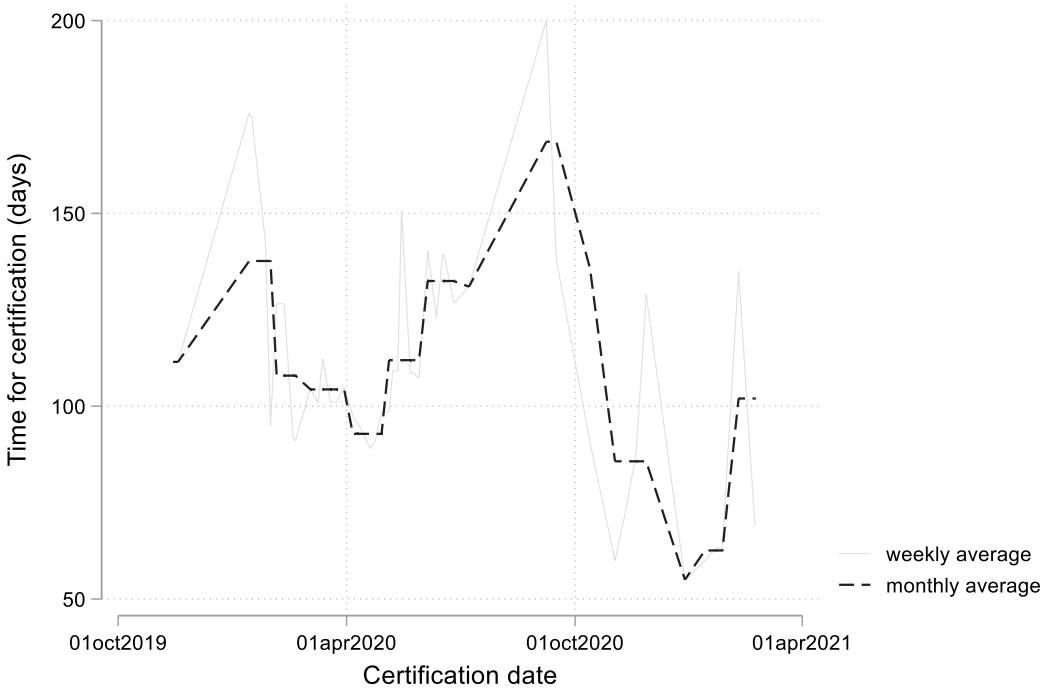

Figure 2. Certification timeline throughout the program existence.

Figure 3. Certification timeline throughout the program existence for VB “A”.

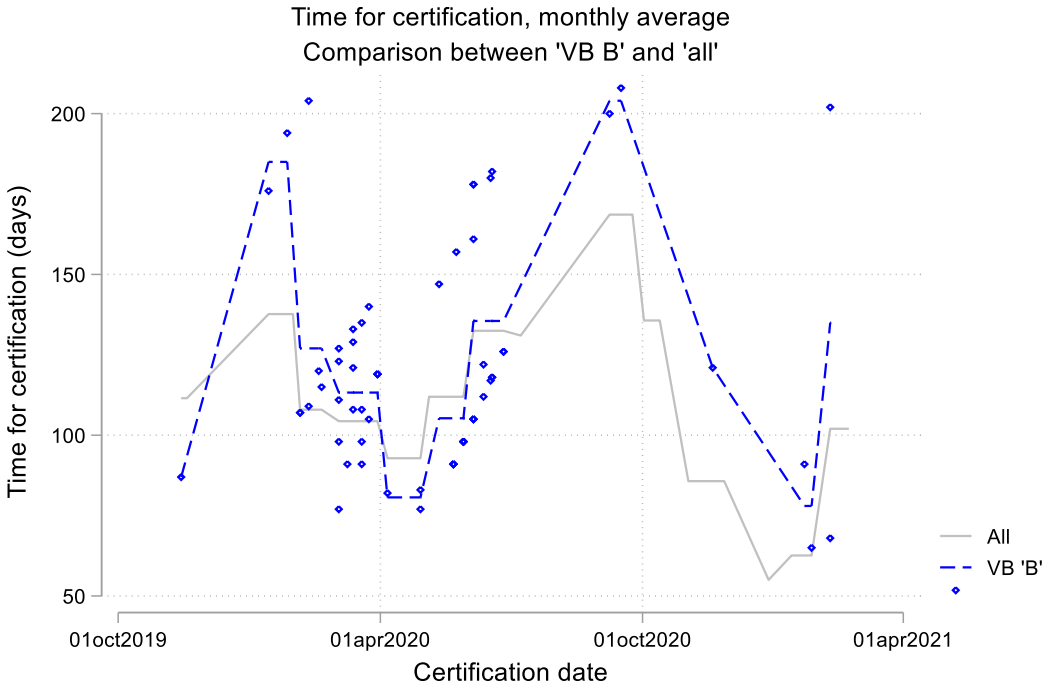

Figure 4. Certification timeline throughout the program existence for VB “B”.

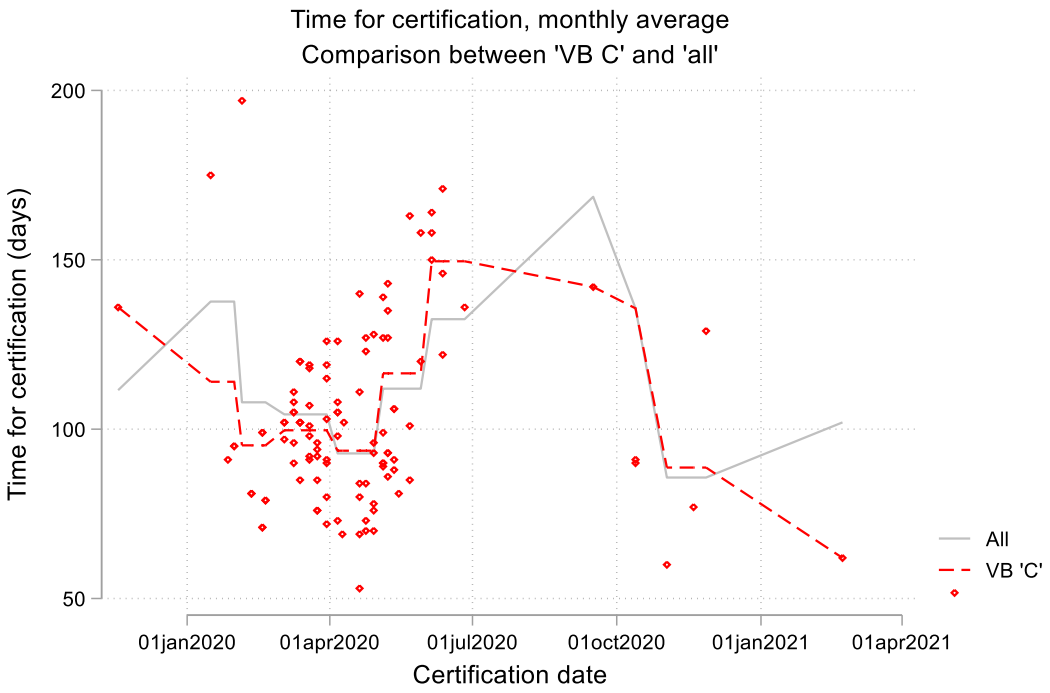

Figure 5. Certification timeline throughout the program existence for VB "C".

Another aspect for analyzing the relevance of a relationship between VB and average NEEA is that a VB could have different geographic coverage NEEA can be related to particularities in climate conditions, which vary from region to region.

Relationship between VB and the Plant Location

The presence of a VB in one region or another could result in a justified difference in NEEA averages for different VBs (Figure 6, Table 7). VB "A" had a greater relative presence in the lowest NEEA region, explaining, at least partially, why VB "A" had the lowest average certification NEEA among the three main VBs. VBs "B" and "C" both had a smaller presence in the North & Northeast region; thus, no geographical

business presence of those VBs would justify differences on its average NEEA certification.

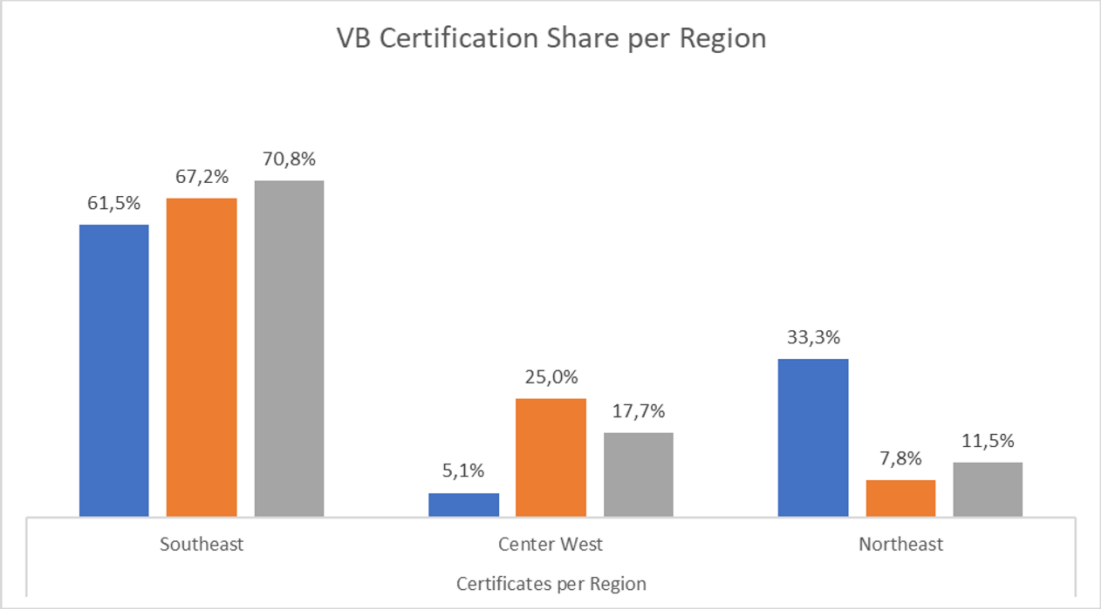

Figure 6. VB share per region. “A”, “B” and “C” respectively.

Table 6. VB certificates per region.

VB	South & Southeast	Center West	North & Northeast
A (N=39)	24	2	13
B (N=64)	43	16	5
C (N=113)	80	20	13

There was a specific geographical condition that made the NEEA lower in certification of plants in the North & Northeast, compared to other regions (Table 7). Thus, a lower outcome is expected for plants in these specific geographic locations.

Table 7. T-test: NEEA per region.

T-test Region and NEEA	NEEA	p-value
South & Southeast (N=147)	59.85	0.49878
Center west (N=38)	60.67	0.19365
North & Northeast (N=31)	57.54	0.01779*
Average NEEA	59.67	--

Relationship between Eligibility Fraction and Biofuel (H2)

There was a substantial difference in mean E% values between two types of biofuel production routes: sugarcane ethanol and biodiesel (Table 8).

Table 8. T-test for eligibility (E%) by biofuel Type, or route.

Biofuel Type	AVG E%	p-value
BIODIESEL (N=25)	45.29%	<0.0001*
Sugarcane ethanol (N=234)	86.49%	

VB and Fertilizers with Nitrogen Report Association (H3)

RENOVACALC contains more than one option for fields when reporting fertilizers, and certain fertilizers are very significant for GHG emissions, particularly those containing nitrogen (Blandford, 2018).

It was important to analyze the specific impacts these fertilizers could have on the certification outcome and whether reporting them in fields that are specific or non-specific for fertilizer products affects the certification outcomes (Table 9).

The reporting options vary from reporting the component quantity of the fertilizers: (N) Nitrogen, (P) Phosphorous, and (K) Potassium in the concentrations according to the specific fertilizing product used, to reporting only the concentrations of these elements in the field “others N” “other P” and “other K”, without specifying N, P, K specific product and its relative proportions. Under those circumstances, it was essential to assess the data and related calculations and find out whether:

- There is a difference concerning the acceptance of this practice between VBs;
- Variation in points for entering data for the same information regarding fertilizers with nitrogen leads to better or worse outcomes, enabling the possibility of “gaming” when the field for reporting is chosen based on the best possible outcome.
- “Gaming” with nitrogen fertilizers N has a quantifiable impact on the NEEA.

Table 9. Fertilizers reporting options on Renovacalc.

	Product	N, P, K concentration
As Specific Product Data	Urea	kg N/ sugarcane ton
	Monoammonium Phosphate (MAP)	kg N/ sugarcane ton
	Monoammonium Phosphate (MAP)	kg P_2O_5/ sugarcane ton
	Diammonium Phosphate (DAP)	kg N/ sugarcane ton
	Diammonium Phosphate (DAP)	kg P_2O_5/ sugarcane ton
	Ammonium nitrate	kg N/ sugarcane ton
	Urea Ammonium Nitrate (UAN) solution	kg N/ sugarcane ton
	Anhydrous Ammonia	kg N/ sugarcane ton
	Ammonium sulfate	kg N/ sugarcane ton
	Ammonium calcium nitrate (CAN)	kg N/ sugarcane ton
	Single superphosphate (SSP)	kg P_2O_5/ sugarcane ton
	Triple superphosphate (TSP)	kg P_2O_5/ sugarcane ton
	Potassium chloride (KCl)	kg K_2O/ sugarcane ton
As Non-specific	Other	kg N/ sugarcane ton
	Other	kg P_2O_5/ sugarcane ton
	Other	kg K_2O/ sugarcane ton

Only Sugarcane ethanol with primary data reported routes were considered.

The results showed that VB “B” accepted less than 10% of fertilizers with nitrogen recorded as non-specific (specific product and its relative proportions. Under those circumstances, it was essential to assess the data and related calculations and find out whether:

- There is a difference concerning the acceptance of this practice between VBs;
- Variation in points for entering data for the same information regarding fertilizers with nitrogen leads to better or worse outcomes, enabling the possibility of “gaming” when the field for reporting is chosen based on the best possible outcome.
- “Gaming” with nitrogen fertilizers N has a quantifiable impact on the NEEA.

Table Table 9), while both VBs “A” and “C” accepted around 20% (Table 10). The difference in average acceptance for “B” compared with “A” and “C” was significant and potentially negatively impacts NEEA outcomes of VB “B”.

Table 10. T-test for fertilizers with nitrogen percentages differences between VBs.

Verification Body	The proportion of fertilizers with nitrogen reported as “other”	p-value
A (N=39)	20.18%	0.7519

B (N=64)	9.16%	**0.0367***
C (N=113)	18.13%	0.9323

Only Sugarcane ethanol routes, with primary data, were considered.

Impact of Fertilizers with Nitrogen on the NEEA

Once verified that there was a relationship between the location used to report fertilizers with nitrogen and the VBs, it was important to analyze whether this created different certification outcomes. There were indications of a direct relationship between a higher % of fertilizers with nitrogen reports in the field "other" and the NEEA (Table 11). Thus, accepting those fertilizers to be reported as "other" with a frequency exceeding 11% is associated with an average 5.3% certification gain compared with those with a

Table 11. Fertilizers with nitrogen proportion range associated with NEEA.

Fertilizers with Nitrogen Proportion reported as Other	NEEAx1000
0 to 11% (N=106)	1.13
>11.01% (N=40)	1.19
% Variation	5.3%

Only Sugarcane ethanol with primary data reported routes considered.

frequency below 11% (Table 1112). This analysis, however, is inconclusive as other factors could be related to a better or worse NEEA. It is necessary, therefore, to obtain a more in-depth understanding of the isolated effect of different ways of reporting fertilizers with nitrogen.

To assess the effect of the fertilizer with Nitrogen alone on the NEEA, I conducted a simulation (Figure 7). The simulation used three RENOVACALCS with the same average production data for the sugarcane ethanol route, with only the fertilizers with nitrogen fields differing from each other. The scenarios applied were: 0%, 50%, and 100% of fertilizers with nitrogen reported as other. The complementary information was reported, on scenarios 0% and 50%, with a linear distribution between fertilizer products with nitrogen (Table 9).

The result shows that the NEEA has a direct, growing relationship with the proportion of fertilizers with nitrogen reported as “other” (Figure 9). As one VB accepts, on average, 9.16% or reports of fertilizers with nitrogen in the field “other”, while the other VBs accept, on average, 20%, it can be seen that VB “B” is the one that betters avoid “gaming” practices.

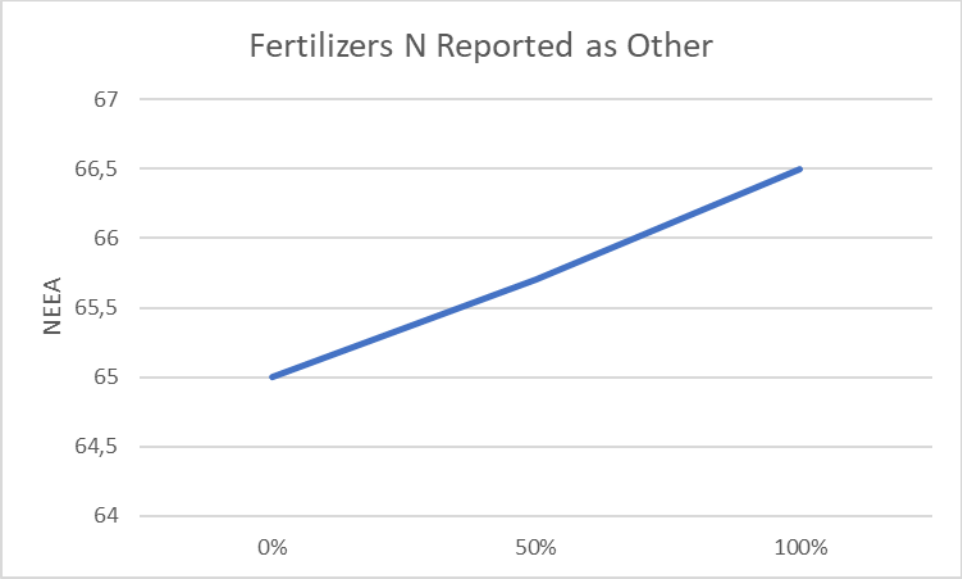

Figure 7. Correlation between % of fertilizers with nitrogen as “other” and NEEA.

Relationship between Plant Size and NEEA

Another possibility to be considered is if economies of scale, where economic size results in more efficiency, could result in greater NEEA. In this case, it would be expected that plant size, with biofuel production of its size measure, would have a positive correlation with NEEA. There was no evidence that a larger producer is more efficient than a smaller one (R=0.08) (Figure 8). Being a large, medium or small producer does not allow any inference about the producer NEEA. Thus, even though the VBs can be related to producers' different sizes (Table 12), this does not explain why a VB would have a better or worse NEEA as a consequence.

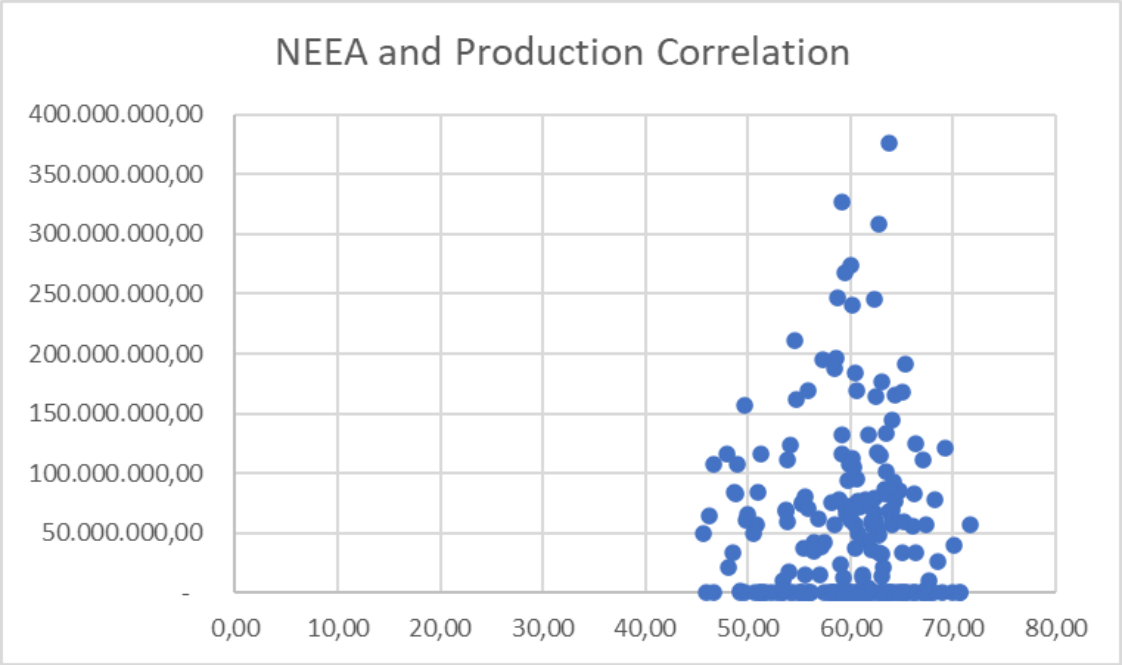

Figure 8. Dispersion of plant yearly production in liters and NEEA.

Table 12. T-test for average biofuel produced and VBs.

Verification Body	Avg Yearly Production of Certified Producers (x1,000 m3)	p-value
A (N=33)	61,362	**0.0390***
B (N=61)	110,509	0.0090*
C (N=104)	85,002	0.3835
Average (N=205)	93,035	--

The average biofuel produced was used as a proxy of the producer industrial size

VB and Agricultural Diesel Consumption Association (H6)

Another important t-test of associations refers to the quantity of diesel reported per ton of sugarcane harvested being related to one or another VB where it should be only firm-specific. The results (Table 13Table) show that the average liters of diesel used to harvest one ton of sugarcane is of interest, as there are differences that could be the result of biases or irregularities in certification practices. VB "C" systematically reports a smaller than average field diesel, which calls attention to an environmental integrity risk.

Table 13. T-tests for field diesel use intensity and VB.

Verification Body (VB)	Average liters/ton harvested	p-value
A (N=20)	4.92	0.3798
B (N=60)	5.20	<0.0001*
C (N=43)	4.56	**<0,0001***
Total (N=123)	4.90	--

Only sugarcane ethanol routes were considered.

Association Between Certification Timelines and Certificate Age (H4)

The following t-test verified whether there were gains in the certification timeline by comparing the first 35 certificates issued and the 35 most recent ones. The aim was to assess whether the average certification timeline has changed over Renovabio' s

existence. The t-test showed that certification intervals for the first certificates were longer than the more recent ones (Table 14).

Table 14. Average time for obtaining certification (older vs recent).

Certificate Age	AVG certification time	p-value
First 35 Certificates	118.80	**0.02525***
Last 35 Certificates	90.40	

Outlier Considerations

The t-tests above were conducted using all the sample data without excluding outliers. The same t-tests were conducted with the exclusion of outliers and the results of interest were strictly the same, therefore, a detailed analysis of outlier inclusion or exclusion justification is less relevant in this particular case. However, the aim of this research was to develop a framework applicable to other programs, thus, a record of the outliers' analyses is available in Appendix 1. It contains the considered definitions for outliers, impacts analysis and other considerations.

Expert Opinions

The questionnaire (Appendix 2) was sent to 21 individuals with thorough engagement and knowledge of the Renovabio Program through different individual perspectives. 13 responded. Responses share according to respondent typology is shown in Figure 9. Unfortunately, the regulatory agencies did not respond.

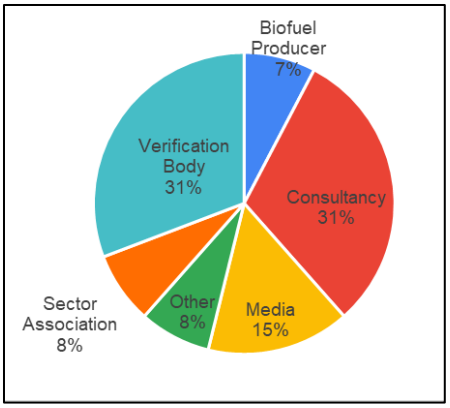

Figure 9. Percentage of participating respondents by role in the Program.

Eligibility and Biofuel Route Association (H2)

Based on the following statement: “The average eligibility fraction (E%) of sugarcane ethanol plants (E1GC) is 86.49%, whilst the Biodiesel eligibility fraction is 45.29%. The difference is statistically significant (p-value<0.0001)”, please answer”: Most of the respondents already knew that the difference of eligibility between sugarcane ethanol and biodiesel existed (Figure 10).

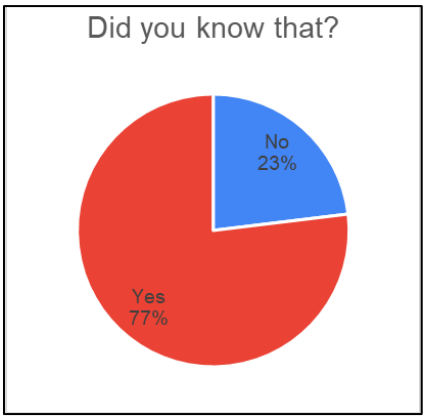

Figure 10. Q&A 1.1: Percentage of respondents' acknowledgment of the issue.

Various reasons were offered for the association (Table 15).

Table 15. Q&A 1.2: Respondent's opinion over the reasoning of the association.

1.2 In your opinion, why does the association (E% and biofuel route) occur?
"Because the agricultural production of biodiesel raw materials (in general, grains) is more fractioned and with more intermediaries to the biofuel plant than agricultural production of sugarcane, which makes the traceability of biodiesel more difficult and costly."
"The [eligibility] fraction may reflect the still existing potential for growth in energy mass associated with the viability of the existing infrastructure."
"While in the sugar-energy sector about 75% of the agricultural raw material (sugar cane) is owned and managed by the ethanol producing units, in the biodiesel sector practically 100% of the agricultural raw material (soybeans, mostly) is acquired from market, resulting in an additional challenge in obtaining eligibility. In addition - and particularly - for the production of biodiesel there are many acquisitions from third parties (either raw material in natura or vegetable oils), and the producer-farmer relationship is not direct."
"Because of the discounts needed for the biodiesel grading."
"Due to the characteristics of each route, where sugarcane has its chain traced and identified from its origin and biodiesel does not, having intermediaries in the middle of the process that makes this identification of the producer difficult."
"Because of the difficulty in certifying biodiesel made with soy oil, which has a much more capillary and distant chain than sugarcane."
"Because there is no methodology for tracking the grain chain (corn and soy)."
"Difficulty in tracking the origin of the soybean used for biodiesel production."
"Perhaps it is the cultivation of other crops that have higher emissions of pollutants in their management."
"Biodiesel producing mills source the grains from many suppliers so it becomes very difficult to analyze the eligibility of all suppliers."
"Difficulty in certifying biomass for biodiesel by using alternative chain of custody methods."
"Verticalization of sugarcane production in agroindustry."
"Due to the complexity of the grain chain in Brazil (logistics, number of agents involved, etc.) that make it difficult to trace the biomass processed in biodiesel production units."

0 respondents did not answer this question.

Respondents mostly expected the difference, as well as most of them considered the condition as risky to the program (Figure 1).

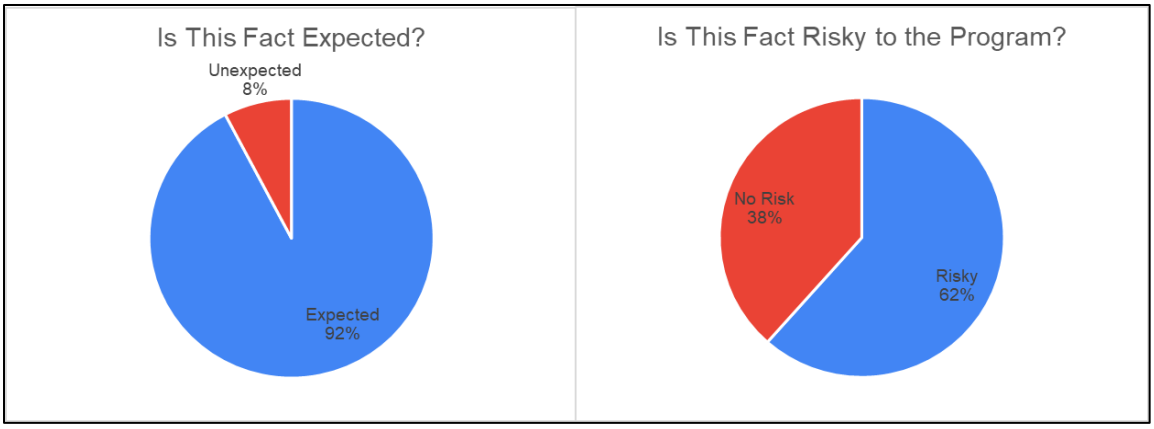

Figure 11. Q&A 1.3: Percentage of respondent's expectation and risk perception.

Respondents acknowledged that the source of biomass for ethanol and biodiesel production impact on the eligibility fraction can vary significantly (Table 16). Only one respondent considered the fact as unexpected. However, three of them provided insights to mitigate this effect, which indicate that the sector deforestation differences might not be the only reason for differences in eligibility by fuel type, adjustments in the program and how it addresses traceability of feedstocks are mentioned as important issues to be overcome to the long-term success of the program.

Table 16. Q&A 1.4: Answers from respondents not expecting the association.

1.4 (if the above answer is "unexpected") What would you do to mitigate, or correct those variables association?
"Check which deductions are being given for the biodiesel and ethanol grade, and check if they are not being too strict with biodiesel."
"Review the biodiesel route and eligibility criteria or set up a working group for the biodiesel sector and route."
"This is perhaps the main challenge of the Program that needs to be overcome so that it is possible to meet the highest decarbonization targets. Given its complexity, I believe that the ideal is to think of solutions, together with all those interested in the Program, to expand the traceability of the grains purchased by the biofuel producing units, without the need to make any requirements of the certification process more flexible."

10 respondents did not answer this question.

VB and NEEA (H1)

Regarding the association based on the following statement: “One of the 3 largest Verification Bodies, delivers an average NEEA above the average of other Verification Bodies. The difference is statistically significant (p-value=0.0425)”, please answer”: only 15% of experts were aware of the issue (Figure 12).

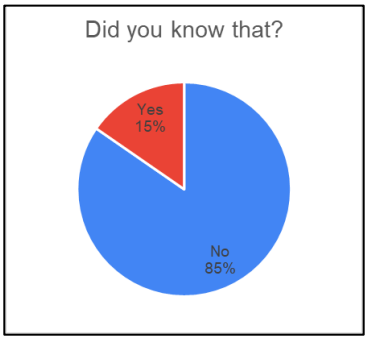

Figure 12. Q&A 2.1: Percentage of respondents' acknowledgment of the issue.

The finding that there is a statistical anomaly that is unknown to 85% (Figure 12) and unexpected for 69% (Figure 13) of experts, at the same time it is understood by 64% (**Erro! Fonte de referência não encontrada.**) of them as a high risk to the program, indicates that a deep discussion on this matter is necessary.

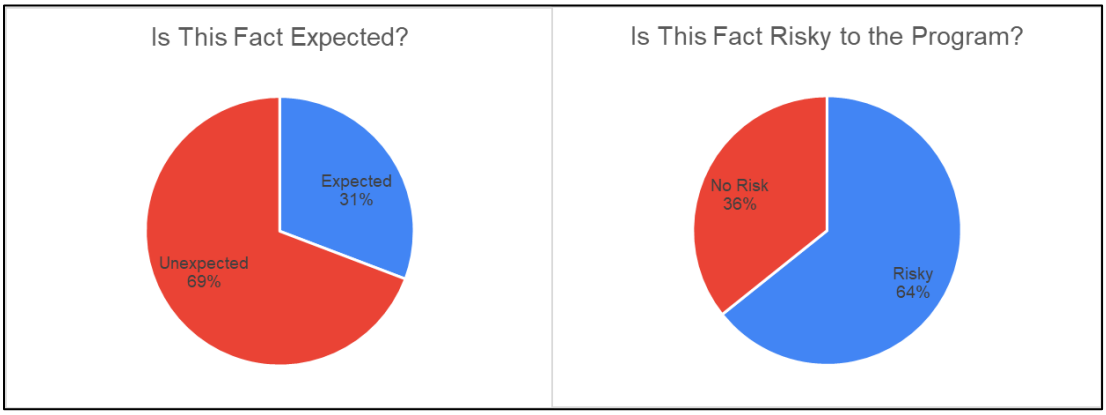

Figure 13. Q&A 2.3: Percentage of respondents’ expectations and risk perception.

The respondent's opinions for the association of VB and NEEA are presented in Table 17.

Table 17. Q&A 2.2: Respondent's opinion over the reasoning of the association.

2.2 In your opinion, why does the association (NEEA and Verification Body) occur?
"So far, due to regional differences regarding the Plants relationship of own sugarcane vs. third party, the CAR and participation in Cbio's, and the mentioned infrastructure."
"Disregarding the cases of residual raw materials, up to a certain level, it is possible that partnerships with intermediaries have been established. Nevertheless, the constant monitoring/supervision of the ANP [National Oil, Gas and Biofuel Agency] is important to guarantee the Program's credibility."
"Because the plant in question used more fossil fuels in the life cycle of ethanol than too much."
"The NEEA result is a characteristic of each production unit, which can be higher or lower according to the eligible fraction and efficiency of each process."
"My bet is that some verification body is not being as independent as it should."
"Due to the lack of adequate statistical methodology."
"I cannot answer, I did not understand the question in the context of average NEEA per verification body."
"Greater knowledge of the verification body, with greater competence."
"Probably because the analysis of the documentation did not consider important variables in the composition of the NEEA, such as, for example, the composition of applied synthetic fertilizers."
"There may be inspection errors that underestimated GHG emissions."
"Different interpretations and applications of regulations by verification bodies."

2 respondents did not answer this question.

In experts' opinion, there is a need to encourage additional verifications to cross-check obtained results and apply sanctions, among other things (Table 18). Those opinions were very important to the framework proposed design (Figure 18).

Table 18. Q&A 2.4: Answers from respondents not expecting the association.

2.4 (if the above answer is "unexpected") What would you do to mitigate, or correct those variables association?
"Assess differences in the methodologies of each verification body and adjust regulation and inspection to resolve differences."
"Constant inspections and adequacy of cases in which deviations are found."
"Inspection and sanctions if there is any irregularity."
"There should be a regular assessment of the work (performance) of the verification bodies. The ANP [National Oil, Gas and Biofuel Agency] itself should have systems for monitoring the performance of the verification bodies (for example, average NEEA) for evaluation and decision-making."
"I would request the Verification Body to demonstrate data analysis, as well as annual audits of the procedures used."
"Improve certification mechanisms using sampling and statistical techniques."
"ANP [National Oil, Gas and Biofuel Agency] control actions and specification of guidelines by the RenovaBio technical committee to train and test auditors, consultants and teams of biofuel producers."
"1) Frequent inspections by the regulatory body [National Oil, Gas and Biofuel Agency], both in certified units and in Verification Bodies; and 2) Regular meetings of the regulatory body with the Verification Bodies to resolve any doubts, discuss potential exceptions not addressed in the Technical Reports and think about improvements in the process."

5 respondents did not answer this question.

Certification Timeline (H4 & H5)

Based on the following statement: "The average delay for the issuance of the first 35 certificates, from public consultation to certification publication, was 118 days. The last 35 issued certificates had an average delay of 90 days. The difference is statistically significant (p-value<0.02525)," please answer": the majority of the respondents were aware of and expected increased speed in certifications over time (Figure 14 & 15**Erro! Fonte de referência não encontrada.**). Also, the vast majority, 85% of respondents did not identify the situation as risky to the Program. (Figure 15**Erro! Fonte de referência não encontrada.**).

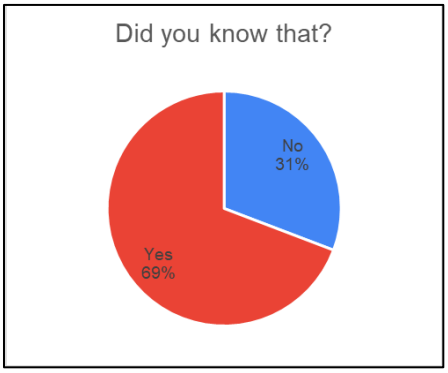

Figure 14. Q&A 3.1: Percentage of respondents' acknowledgment of the issue.

Respondent opinions on this topic are presented in Table 19 & 20.

Table 19. Q&A 3.2: Respondent’s opinion over the reasoning of the association.

3.2 In your opinion, why does the association (age of submission and certification timeline) occur?
“Probably because the first certifications encountered difficulties that were not initially foreseen, but which later became more widely known among producing agents and verification bodies.”
“Redundancy….LOL. Fully understood.”
“The peak of certification requests was reached at the beginning of the program, entering a more stable pace in the most recent period.”
“Because of the characteristics of land use, fossil fuels and production efficiency of each plant.“
“Due to the learning of all program participants, it tends to become a faster process.”
“There is greater knowledge of everyone involved with the certification process.”
“Learning and evolution in certification.”
“More experience from all participants in the process.”
“Due to the acquisition of greater experience and understanding of the program.“
“Both the Verification Bodies and the biofuel producers have become more familiar with the program and the necessary supporting documents. However, it is worth noting that very quick checks suggest a decrease in the rigor of the analysis.“
“Learning gains of mills and inspection firms.“

“Learning curve and certification demand reduction after March 2020.“
“High demand peaks to the ANP [National Oil, Gas and Biofuel Agency] team.”

0 respondents did not answer this question.

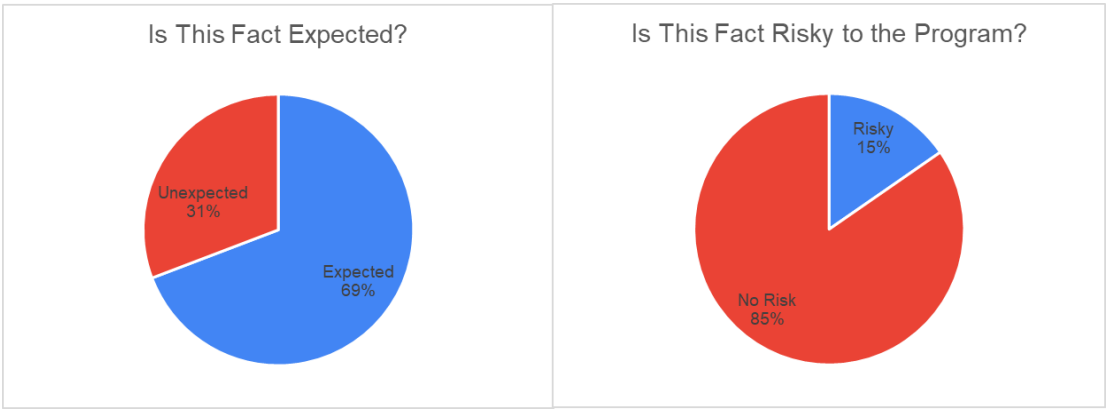

Figure 15. Q&A 3.3: Percentage of respondents’ expectations and risk perception.

Table 20. Q&A 3.4: Answers from respondents not expecting the association.

3.4 (if the above answer is “unexpected”) What would you do to mitigate, or correct those variables association?
“High verification speed compromises quality. It is necessary that it becomes, as usual procedure, the annual supervision of the Verification Bodies.”
“Reinforcement of methods for approval of certifications in order to prevent fraud.”
“Greater transparency on procedures and criteria applied for certification. Eventually, sharing the priority matrix in the assessment for certification in order to make execution times more homogeneous in a high variability environment of biofuel producing companies.”
“Increase the regulatory agency’s assessment team and automatic intermediate validations (completion of documentation, renovacalc fields, etc.)”

9 respondents did not answer this question.

Adequate Reporting of Fertilizers (H3)

Based on the following statement: “Fertilizers inputs can be made at different spots of the Renovacalc. Nitrate (N) fertilizers are particularly important for greenhouse

gases emissions. Inputting fertilizers (N) at specific fields, such as (Ammonia, MAP, Urea, etc.) results in a 6% higher GHG emission when compared to its input on the general for (N).

There is one VB, among the three largest, that only accepted 9% of N fertilizers reports as others, whilst the other two largest VB accepted about 20% of N fertilizers as others (N). The difference is statistically significant (p-value<0.0366)," please answer:

The responses referring to the type of report of fertilizers with nitrogen show that this is a topic which not even experts are very familiar with (Figure 16). Only 15% of them were aware of and expected that there would be an association between the field for reporting fertilizers with nitrogen and the NEEA, nor with the VB different approaches over the percentage of acceptance of fertilizers with nitrogen reported as "other" (Table 21 & 22). The majority (54%) viewed the practice as a risk to the environmental integrity of the program (Figure 17).

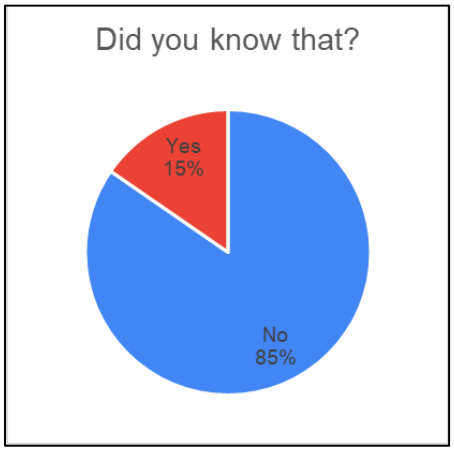

Figure 16. Q&A 4.1: Percentage of respondents' acknowledgment of the issue.

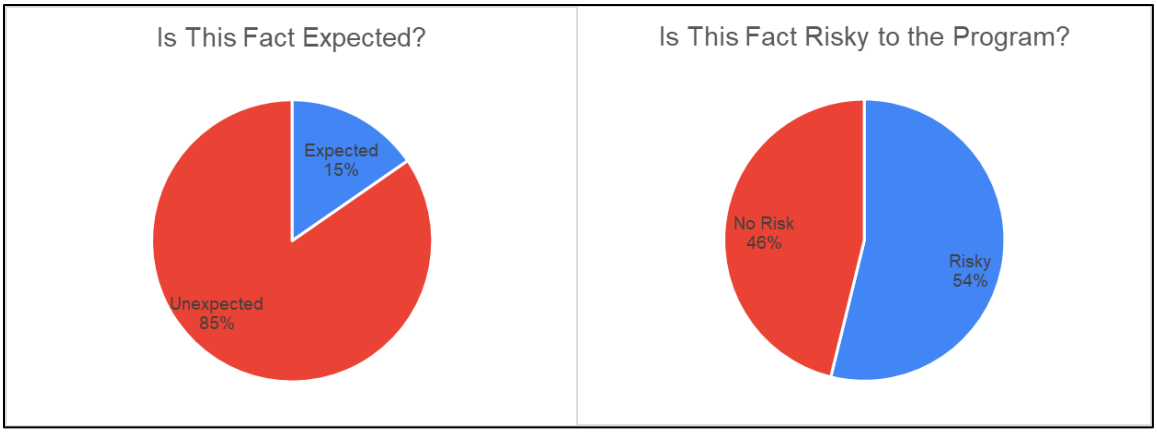

Figure 17. Q&A 4.3: Percentage of respondents' expectations and risk perception.

Table 21. Q&A 4.2: Respondents' opinion over the reasoning of the association.

4.2 In your opinion, why does the association (of fertilizers with nitrogen and inspection firm) occur?
"Probably due to a loophole in regulation, which makes the classification of fertilizers in RenovaCalc ambiguous."
"Redundancy."
"I don't know, but it would be reasonable to have some comparison and adjustment program for information releases at RenovaCalc."
"Due to the use of fertilizers or some gap in the calculation tool."
"It is data that depends on each production unit, how it is controlled and how it is entered in the spreadsheet, according to the rules. In the case that is generating this difference, the ideal would be to review the program's rules to standardize the information."
"Because the verification body is concerned about the result of the company that hired it and is using the limits of the rules to obtain that result."
"Lack of pattern in item definition."
"I will answer the question in the context of reporting fertilizer as "other". I can't say why this happens, but it needs to be followed up. And it can easily be followed up by the ANP [National Oil, Gas and Biofuel Agency], for later decision-making on how to react."
"For a greater degree of demand."
"Negligence in the accuracy of the analysis and eventually collusion with the biofuel producer."
"Doubts and inaccuracies about filling out the worksheet."
"Lack of training of auditors and ANP [National Oil, Gas and Biofuel Agency] on the subject."

1 respondent did not answer this question.

Table 22. Q&A 4.4: Answers from respondents not expecting the association.

4.4 (if the above answer is "unexpected") What would you do to mitigate, or correct those variables association?
"Improve the regulation for filling RenovaCalc to ensure greater detail in the classification of fertilizers. The greater the specificity of the elements included, the greater the credibility of the program."
"Comparative information release program at RenovaCalc."
"Review necessary data for fertilizers and review equations."
"Changing the rules, inspection and sanctioning."
"Standardize item inputs."
"As I said above, this can (and should) be monitored by ANP [National Oil, Gas and Biofuel Agency], for subsequent decision-making on how to react. Probably with certification performance evaluation."
"Just do not accept the fertilizer report in the other item. Component specification must be mandatory."
"Improve filling manuals and worksheets."
"ANP [National Oil, Gas and Biofuel Agency] define a proposal to adjust the conduct of verification bodies now that the understanding on the subject allows proper application of the regulation by all verification bodies and a large part of biofuel producers."
"1) Frequent inspections by the regulatory body, both in certified units and in Verification Bodies; and 2) Regular meetings of the regulatory body with the Verification Bodies."

3 respondents did not answer this question.

Experts had a final opportunity to express themselves in any regard (Table 23).

Table 23. Q&A 5: Open questions for additional comments.

5. Please provide any comment you understand to be relevant.
"Congratulations for the strategy in the search for coherent answers by repeating the same question. A question that will have a greater degree of importance and significance due to the professional's geographic area of activity."
"Verification Bodies and Biofuel Producers must be audited, at random, on a regular basis."
"I believe it is important to evaluate the variables considered over time, in an attempt to verify whether some risks described in the research are being mitigated since the beginning of the Program."

10 of them did not answer this question.

Chapter IV

Discussion

This section contains an in-depth discussion of the relevant results. The discussion aims to identify effective risks, based on the statistical anomalies identified, and propose ways to improve the Renovabio Program in a structured analytical way. Results are presented for each hypothesis under its specific context, with additional details of its supporting background, whenever required.

The results assessed are:

- The relationship between the NEEA and the choice of VB (H1),
- The relationship between the type of biofuel produced and the E% (H2),
- The relationship between the position of the fertilizers with nitrogen report and the NEEA (H3).

The other hypotheses (H4 to H6) are not discussed as the statistical testing referenced any acknowledgeable anomaly in the results chapter.

Association Between VB and NEEA (H1)

As the NEEA expresses greenhouse gas emissions avoidance per unit of energy, biases that increase the NEEA pose a high risk to the Program as the higher NEEA is, the lower the emissions registered per unit of energy originating from biofuel and, in consequence, the more CBIOs are issued. Faults in the NEEA measurement can seriously compromise the environmental integrity of the program.

The t-test revealed an inappropriate association between a higher NEEA with the VB which certified the operation, which promotes significant bias. It is therefore important to analyze whether there are causal relationships between hiring a specific VB and the certified NEEA.

Given that logically, the VB is contracted first and then the NEEA is certified, if there is causality it can only be viewed as hiring a VB leads to better, or worse, outcomes; in other words, more or fewer CBIOs could be earned in the same operation, depending on the VB hiring choice. Of the three largest VBs, “C” is that which delivers, on average, the best NEEAs. This invokes a more in-depth analysis. Would it be possible that there is a legitimate reason for this relationship, invalidating the hypothesis that such association is legitimate?

Statistical evaluations with observational data are subject to what is known as self-selection bias. This is a phenomenon in which a causal association may not become apparent in a correlation analysis or, alternatively, a correlation relationship could suggest a non-existent causal relationship. For example, choosing a random bus stop to sample a group to infer about population height may seem appropriate, however, if it is in front of a secondary school and the research is conducted at a time coinciding with the end of the school day, a bias will likely occur, as the children's frequency will lower the sample height average.

Back to (H1), a possible reason for this association to occur legitimately would be that one VB is operating in a specific sector of the market which results in better NEEAs. For example, a larger plant could be expected to be more efficient and, therefore, if a VB has proportionally more contracts with larger companies than other VBs, that could be an

explanation for the average NEEA of this VB exceeding that of the others, without any inconsistency or risk to the Program.

The approach used to assess size and possible economies of scale resulting in improved NEEA was the production capacity in liters of each certified plant as a proxy of producers' size. This fact, however, is not verified. There was observable segmentation between VBs and the size of company certified but the VB which on average attended producers with higher production capacity is VB “B”, and VB “A” serves those with lower capacity. VB “C”, associated with higher average NEEA outcomes, serves medium-sized companies (Table 12). Furthermore, no correlation was identified between NEEA and quantity produced (Figure 8). Thus, certifying a larger or smaller producer should not result in a better or worse NEEA, and it does for VB “C”.

Another possible self-selection could happen if there were geographical associations. A VB with more presence in a region where production is more efficient would justify its certificates to have an average different NEEA. A relationship was observed between NEEA and geographic region. This was due to differences in productivity between regions. Operations in the North and Northeast result in lower NEEA (Table 7).

VBs “B” and “C” have a similar penetration per region and do not show statistically significant differences in their certified NEEAs, ruling out the possibility of a justified bias due to geographic location between these VBs. VB “A” has a higher proportional presence in the North & Northeast regions, which explains, at least partially, why VB “A” has a lower NEEA certified average. Thus, there is no justified relationship

between the better NEEAs certified by VB “C” and its geographic presence in the market (Figure 6).

It is important to note that self-selection phenomena, situations that might have a plausible explanation for the legitimate association of variables, are not always identifiable or quantifiable. There may be other practical reasons explaining the reasonableness of this association that this study did not identify. Thus, assuming that no self-selection phenomena have been missed, there is a strong indication that the association between VB and NEEA is effectively caused by the choice of VB. This is undesirable.

The vast majority of the experts, 85%, who responded to the questionnaire were not aware of this situation (Figure 12). This fact was also considered by the majority of respondents as unexpected (69%) and posing a high risk to the program (64%) (Figure 13). It would be difficult for such a situation to arise from unintentional faults or unavoidable biases. Unintentional faults tend to generate random errors. Random errors are sometimes above or sometimes below average, they cancel each other out not affecting the average, which would not create a better or worse NEEA for VB “C”. The evidence indicates the error may not be random, as it systematically produced gains. A possibility to be investigated is that the VB is not operating with effective and necessary independence. The results suggest the need for supervision from the regulator.

Relationship Between Type of Biofuel and Eligibility Fraction (H2)

The main aim behind the creation of the carbon market is to enable economic forces through the incentives created to allocate resources dynamically to encourage emissions mitigation with greater economic efficiency (World Bank (2019a).

It is important to ensure equality between agents, on both the supply and demand side for CBIOs, for the Renovabio Program market to function properly. Demand is determined by regulation targets. There is a yearly aggregate target, which is allocated between fuel distributors according to an objective rule, proportional to their contribution to fossil fuels' GHG emissions. The calculation baseline for the target is the previous year's energy share of each distributor in the fossil fuel matrix. Thus, the more fossil fuel energy a distributor operates, the more CBIOs they must purchase to meet their target in the following year. I see no issue on the demand side.

On the supply side, however, current rules and processes are not being able to ensure balance or equality of opportunities for biofuel producers. This means that for the same emission reduction offered by different biofuel producers, CBIOs gains for each producer can vary. Eligibility ruling has an enormous impact on this variation between biofuel routes (Table 8).

A fundamental aspect of generating a CBIO is ensuring that the reduction in emissions in the biofuel lifecycle does represent the reality of reduced emissions through replacing fossil fuels. A CBIO represents one ton of CO2 emission avoidance as the result of replacing a quantity of energy from fossil fuels, with a renewable one. As the lifecycle assessment includes the agricultural stage, there is a risk of indirect emissions. If a producer deforests an area to produce biomass and convert it into biofuel, there will be fugitive emissions from such deforestation, which is not captured by RENOVACALC. This could affect the Program's environmental integrity.

The regulating agency is aware of this and has established an eligibility criterion to address the problem. It must be proven by the biofuel producer that there was no

deforestation in the agricultural area that yielded the biomass used to produce its biofuel. (National Oil, Gas and Biofuel Agency, 2020d). By applying current rules and procedures to determine the eligibility fraction over the processed biomass, a relevant difference in the averages for biodiesel made from soybeans and ethanol made from corn, below 40%, compared with sugarcane ethanol, above 80% is found. (Table).

The eligibility fraction of biofuels made from grains is less than half that of sugarcane ethanol. This would only be appropriate if the areas with the grain had a deforestation pressure twice that of the sugarcane, which is very unlikely. A recent study by postgraduate researchers indicates that the fraction of non-deforested areas planted with sugarcane is 98%, while that of soybeans is 72.7% (Agro Insper, 2021).

Thus, the reason for the eligibility differences in the Program seems to be more linked to the applicability of the Program rule than to actual field conditions. Understanding the differences in the field practices for each route: sugarcane ethanol and soybean biodiesel is important to propose adjustments in the regulation.

Sugarcane, being a type of grass, occupies a great deal of space with little mass as its density is low. Thus, it is only economically viable to be transported if the plantation and the plant are geographically close. In the sugarcane sector, the leasing and partnership model is quite common, in which the biofuel producer operates the planting and harvesting in favor of the sugarcane producer. This also depends on geographic distribution over short distances, enabling this business model to be feasible. Long-term supply contracts are common, there is a lasting relationship between the sugarcane suppliers and the plants. It is also common for plants to have their own sugarcane fields, in contrast to the situation with grains. Finally, sugarcane always goes to a plant that

produces sugar and/or ethanol, there are no other commercial-scale uses for this agricultural product.

Another important characteristic to note is that sugarcane plantations, in general, are large compared to soybean plantations. There are therefore fewer sugarcane suppliers than there are for soybeans for the production of ethanol and biodiesel, respectively. Once the rules require all biomass providing areas to be georeferenced-analyzed in terms of deforestation, that census analysis is much easier and more feasible for sugarcane than for soybeans and other grains.

The soybean supply chain for producing biodiesel is completely different. Firstly, soybeans have a much higher density than sugarcane, and they can therefore be transported across the country without this being economically unviable.

In contrast to sugarcane, which is moist and spoils if not used within a few days of harvesting, soybeans can be stored for long periods, without losing the physical-chemical characteristics necessary for producing biofuels. As they are not perishable, this leads to many traders operating in the market, storing grains for future sale. In Brazil, it is rare to see soybeans sold directly from the plantation to the biodiesel producer with no traders involved. Traders sometimes provide seeds, technical assistance, and finance agricultural production. Traders, of course, have no interest in providing information on the origin of the soybeans, as such silence is an important part of their business model.

On the other hand, if the grain field origin information is not shared, it is difficult to demonstrate the eligibility status of those grains. This is such an important fact that some traders, who are also biodiesel producers, only adhered to the Renovabio Program when the regulator ruled that information on the agricultural stage did not have to be

disclosed in public consultation, in the update of Technical Inform No. 2, item 4.2 of October 09, 2019. The first soybean biodiesel plant was certified on 05.05.2020, at which point more than 120 ethanol plants had been already certified (National Oil, Gas and Biofuel Agency, 2020a).

Additionally, and different from sugarcane, soybeans can be used for a range of purposes. They can be exported *in-natura*, used to produce oil for food purposes, produce animal feed, or be used in 'transesterification' the process by which soybean oil is transformed into biodiesel.

Another important difference, and perhaps that which most impacts difficulty in certifying a greater eligibility fraction, is that soybeans have to first be crushed and turned into oil, before being converted into biodiesel. There are two industrial stages, rather than just one, as is the case with sugarcane. Today, in Brazil, there are 98 soybean crushers, most of which are independent, in other words, they are not owned by biodiesel producers. Thus, biodiesel producers usually buy soy oil rather than soybeans, not knowing where the grains come from, thus, not being able to make them eligible for the Program.

Finally, there are many more soybean producers than sugarcane producers in Brazil. It is common, then, for a biodiesel plant to have many more areas supplying feedstocks than a sugarcane ethanol plant has. This is evidenced by the fact that there are around 243 thousand soybean producers (Aprosoja, 2021), whereas there are around 74 thousand independent sugarcane plantations (Sugarcane, 2021).

It is practically impossible for a producer of biodiesel from soybeans to ensure that a quantity of oil was purchased from a crusher, who in turn purchased the soybeans

from a trader, who in turn purchased them from a specific area in which there was no deforestation. Thus, biodiesel producers focus on certification of the production with waste inputs: such as residual fat and used cook oil as, according to the program rule, for waste inputs, it is not necessary to assess the lifecycle of the agricultural chain with its respective eligibility criteria. All biodiesel production using residual raw materials is 100% eligible. The biodiesel producer's only obligation is to track distance, and associated GHG transportation emissions, from suppliers of residual raw materials to the biodiesel plant.

The practical result of this is that, under the rule in effect, it is much easier for sugarcane ethanol producers to demonstrate eligibility than for producers using soybeans, regardless of the actual deforestation of each route.

The rule in effect for the declaration of eligibility requires that, for the agricultural stage, the applicant has to analyze all providing areas, classifying them as eligible or not, to then subject only those that are eligible to VB analysis. The VB, in turn, can use a sampling technique, pursuant to the regulations (National Oil, Gas and Biofuel Agency, 2020d):

> When the Verification Body opts to sample by verifying the eligibility criteria for the biomass producers, the ten largest eligible biomass producers submitted by the biofuel producer should be audited. The others can be sampled, considering the list of eligible producers submitted by the biofuel producer, excluding the abovementioned ten largest... and those producers declaring they did not supply anything in the period audited... ineligible producers should not be included in the sample universe...For each biomass producer included in the sample, all eligibility criteria must be audited.
>
> …

Further, given the program parameters a sampling size will never be higher than 68 areas plus the 10 largest providers, regardless of the number of providers, commonly,

whenever high reliable automated information systems are in place, the chance of an error is considered to be equal or lower than 10%, which is a common practice in reasonable audits. In such cases, samples will never be over 30 observations. This can be confirmed by applying the following sampling size formula with the most conservative available parameters: p= 0.10 and q=0.90. Sample sizes would be, respectively 68+10 and 30+10 (Spiegel,1993; Sullivan, nd):

$$n = \frac{N \times p \times q \times (V)^2}{[p \times q \times q(V)^2 + (N-1) \times \varepsilon^2}$$

where: n: Sample size
N: finite Population
p = (1-q): Population proportion with study characteristic of interest
q = (1-p): Population proportion without study characteristic of interest
V: Significance level (Critical value for a monocaudal normal approximation within a 95% confidence interval = 1,645).
ε: Margin of Error

The sample parameter (p) is the expected probability of an error meaning that this is the probability of finding ineligible an area declared to be eligible. The parameter (q) is the opposite.

Should the VB sampling identify one or more ineligible producers on the list declared as eligible by the biofuel producer, the following procedures should be applied:

- Ineligible producers must be removed from the list of eligible producers;
- The VB must require the biofuel producer to check again all the records and data on the list of eligible producers;
- The biofuel producer must check the list of eligible biomass producers, recording the document review and identifying all alterations, before resubmitting to the VB;

- The VB must undertake a new audit of the list of eligible biomass producers and, in the case of statistical sampling, eligible biomass producers already verified in the first sample and whose details remain unaltered must be excluded from sampling. In other words, the VB will not repeat the audit of the same biomass producer.

Should the VB find that the second sample contains one or more ineligible biomass producers on the list of eligible ones submitted by the applicant, only biomass producers effectively verified by the VB can be considered eligible. In other words, there will be no third sampling to check the list of eligible biomass producers.

Based on this ruling, VB sampling is used to confirm a census analysis from the applicant. This is not the best use of statistics. Analyzing thousands of areas is subject to human error. Only one mistake captured by the sampling procedure invalidates the entire analysis. Further, the regulatory agency is not engaged in the sampling procedures; it is up to the VB to determine sample size and its randomness. What if a sample is not random? If a VB accepts a pre-selection of areas or replaces a non-eligible area that was detected by an eligible one. Those type of misconduct is almost impossible to detect since there is no effective way to *ex-post* evaluate the randomness of one sample.

Establishing a procedure to not allow this situation to happen, would avoid frauds and other mistakes that biases samples and potentially corrupt the environmental integrity of the Program.

Association Between VB and Agricultural Diesel Reporting

The results for the association between VB and the amount of field diesel reported per harvested ton of sugarcane showed that VB “C”, which also had the best-certified

NEEAs, also certified information on average diesel use in the agricultural stage that was statistically different from the others. In this case, the diesel reported was lower than the average, which is one of the reasons the NEEA is better (Table 13).

This discrepancy could be related to audit practices. Documentary records of diesel and other fuel consumption must be added and the sum divided by the total biomass collected in tons, thus giving an indicator of fuel use per ton of sugarcane harvested. Possible omission of a record can only be detected if the VB team is aware beforehand of what is and is not acceptable as a parameter of diesel per harvested ton. In other words, it is hard to audit information or records that can´t be seen. However, it is the responsibility of the VB, using its professional judgment, to refute data that do not seem compatible with reality, as well as to follow with the auditing principle of "completeness", which requires the VBs to assure information is complete.

On the other end of the spectrum, we have VB "B", where the certified average diesel per harvested ton is above what would be statistically expected. This means that there is also an association between the quantity of diesel used in the field per ton in the field and this VB. However, the certification outcome is worse, negatively affecting the NEEA. As the assessment is based on documents, it is not possible to overestimate fuel use measurements, only underestimating them is possible.

Having one VB associated with lower-than-expected use of diesel in the field while another is associated with higher-than-expected use reflects a difference between VBs in the rigor of analysis and acceptance of document records proving the data entered into the calculator. It seems there must be information on diesel use missing in most audits.

Based on this finding, it is relevant for the regulator to select a statistically relevant set of plants certified by VB “C”, which has a low proportion of diesel use per ton of sugarcane and inspect those certifications. Also, taking VB “B” results and procedures as a benchmark is desired. If one VB can validate more accurate and complete information, it is then recommended that other VBs should also be able to promote more reliable audits.

Relationship Between the VB and How Fertilizers are Recorded (H3)

The results of the analyses referring to how nitrate fertilizers are entered into the RENOVACALC show a significant difference in the results. Given the impact of these fertilizers on the NEEA, VBs must handle them in the same way when they audit, accept or reject this information.

VB “B” accepts the lowest proportion of use of the “other” field to report fertilizer with nitrogen, leading to a lower NEEA outcome than those which record a higher proportion of those fertilizers in the “other” field (Table 11). The other VBs accept more than double that the accepted by VB “B”.

In RENOVACALC, fertilizers with nitrogen can be reported in different fields. One option is to enter the data of products used for fertilization and soil correction with the composition of nitrogen, namely: urea, monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium nitrate, solution of urea and ammonium nitrate (UAN), anhydrous ammonia, ammonium sulfate, and calcium ammonium nitrate (CAN). An alternative to entering fertilizer with nitrogen in the calculator is to enter the information of the chemical element nitrogen (N) into the field “other” rather than the specific field of the products described above.

This study found that there was gain from reporting fertilizer with nitrogen as "other". In cases in which this occurred more frequently, there was a mean increment of 5.3% in the NEEA (Table 11). If reporting a higher fraction of fertilizers with nitrogen as "other" than in the fields for the specific nitrogen-containing products gives a better outcome, "gaming" might occur, through deliberately choosing to enter the same information into different locations of the spreadsheet to obtain better outcomes.

RENOVACALC gives different emissions results for how the same quantity of the element nitrogen contributes to carbon intensity, which is not desirable. Before attempting to correct the problem, it is important to understand the origin of these differences. Upon analysis of the way RENOVACALC functions, we can see that for calculating emissions related to the application of products with nitrogen at the agricultural stage, as they are all imported, the emissions for transporting these products to Brazil are considered, whereas when reporting nitrogen as "other" includes solely emissions of the element nitrogen and not the origin of a specific product. In the latter case, emissions from transport are not considered (National Oil, Gas and Biofuel Agency, 2020g). The practical result is that not knowing the origin of the fertilizer with nitrogen represents an advantage in the certification.

Based on the principle of environmental integrity and that lack of information about the products used should result in the adoption of parameters yielding more conservative results, as occurs when RENOVACALC standard data are used -- the standard data do not need to be proven, they are determined, conservatively, by RENOVACALC itself -- it is important to have a similar approach to fertilizers with nitrogen reported as "other". Not knowing where it comes from should allocate the

transportation emissions from the most distant available source of it, disincentivizing its use.

Based on the valuable conceptual and practical elements that fed the discussion and results above for the Renovabio case study, the following section presents recommendations for a structured framework to assess and improve the Renovabio Program and other similar ones relevant to GHG gases mitigation.

Conclusions

Looking for statistical anomalies in the Renovabio database has proven to be an effective strategy for identifying potential faults and guiding efforts to Program's improvement. The results suggest possible breaches of the environmental integrity in the Renovabio Program that urges for a solution. By objectively demonstrating that there are significant failures, the results presented here are useful to support the regulator in addressing program design loopholes.

The existence of potentially inappropriate conduct by a VB is corroborated by warnings issued by the Renovabio Program regulator on two occasions both of which led to the application of sanctions. The first was on 12/23/2019 for "*Exercising activities that compromise impartiality or confidentiality of information*." The second was issued on 03/13/2021 for "*Incidence of non-compliance which, due to the significance, extent or amount, has resulted in lack of confidence in the activities conducted by the Verification Body*" (National Oil, Gas and Biofuel Agency, 2020j). However, without a clear framework to assess the flaws, there is no guarantee that positive changes will ensue.

Thus, the approach used in this dissertation to pre-select possible associated variables, where there should not be an association, has proven effective. The statistical anomalies observed are in line with the regulator's warnings of inappropriate practices.

Based on the identified associations, I conducted a more in-depth analysis to confirm the hypotheses that the associations were not justified. The possibility of self-selection invalidating the statistical analysis, and the survey with experts regarding their opinions on the facts, were studied meticulously and included in the results.

From the six hypotheses, three were found to have statistical anomalies that motivated the following recommendations for adjustments to the Renovabio Program rules and procedures, aiming to improve outcome quality and the Program's environmental integrity:

Changes to the Rules to Improve the Eligibility of Biodiesel (H2)

Aiming to minimize the problems and costs of assessing eligibility, I recommend a change to the rules which would both ensure environmental integrity, be difficult to be frauded and which effectively reflects eligibility in the areas supplying biomass, as well as improve environmental integrity by greatly reducing the VBs sampling margin of error.

The following recommendation preserves the principle of equal participation between producers of the main types of biofuels in the Program: sugarcane ethanol, corn ethanol and biodiesel made from grain. The CBIOs issued must reflect the reality of the sectors, ensuring the distribution of resources appropriate to the environmental benefit generated.

For the program, the least risky and lowest cost way of doing this is to use statistical methods to determine one eligibility fraction for the producer and another for the VB, independently.

Rather than the biofuel producer having to analyze all the areas, separating them into eligible and non-eligible, and submitting only the eligible ones to be considered by the VB, whose sample will not include more than 68 areas, both would sample 100 areas from the entire universe of the biomass suppliers, for a total of 200 unrepeated sampling areas. Using this technique would reduce the margin of error as there would be a total of 200 areas analyzed, rather than 68.

To avoid possible manipulation of the sample randomness, the regulator must support the selection of areas, before analysis of eligibility conditions. This method would reduce the margin of error from 10% to approximately 8%, increasing environmental integrity.

Finally, the regulator can also determine that, of the two samples, the one with the lowest eligibility fraction is the one that will count. Although through this technique it is not possible to state which specific biomass providing area in the universe is or is not eligible, there is a significant increase in the program's environmental integrity by acknowledging an aggregated eligibility with less error.

Rule Changes to Improve Nitrogen Fertilizers Reporting (H3)

The recommended solution, based on the observations (Table 10 & 11), is presented below:

- Accept a maximum fraction percentage for reporting fertilizers with nitrogen as "other", whilst also ensuring flexibility in reporting, but avoiding exaggerated use

or differences in acceptance by the VBs. I suggest 5%, as this figure follows current practical certification audit conditions of VB “B”, the most rigorous in this type of analysis for certification.

- Review Renovacalc to include conservative transport emission factors in calculating emissions per energy unit in the fertilizers with nitrogen as “other”, ensuring there is no possibility of gaming to benefit through less precise reporting of these fertilizers.

If it is not possible to ensure that less than 10% of fertilizers with nitrogen are related in the field “other”, the applicant must migrate all agricultural stage information to standard data, which is more conservative and thus ensures the environmental integrity of the report. This option should be avoided, as migrating the information to standard data could result in adopting standard parameters not only for fertilizers but also for all input information, such as fuel use, burned area and others, which would substantially reduce the NEEA.

Expert responses to the question on the association between the specific field for reporting fertilizers with nitrogen and the VB support the conclusions presented here. Only 15% of them were aware that the choice of the field for reporting fertilizers with nitrogen modified the result (Figure 16) while 54% classified the problem as posing a high risk to the program (Figure 17). The recommendations made to solve the problem involved encouraging adjustments to the calculator and ruling.

Proposed Generalized Framework

The analysis of the association of variables where they should not exist, stakeholders’ consultation, and regulation desk review that motivated proposals of

adjustments to the Program, led to a framework that can be applied to Renovabio and other carbon emission reduction cap-and-trade programs abroad (Figure 18).

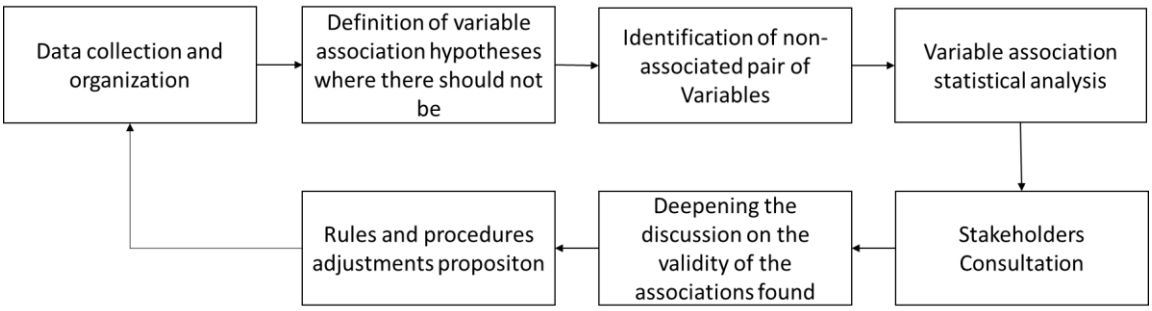

Figure 18. Quality assurance general framework.

Collecting data, public or not, is the starting point that will support the definition of variables and association hypotheses (Figure 18). Gathering and organizing data based on the expectation of their association is the starting point and cornerstone of the analysis. It is critical to understand, for each variable, if an association is expected or not. The proposed approach is to identify and analyze variables from which an association is not expected.

Generally, VB choice should not be linked to the certification result in any program. However, depending on the program's architecture, adjustments to the hypothesis and determination of pairs of unassociated variables may need to be adjusted. For instance, if a program has only one VB, or if verification is made directly by the regulator, it will not be possible to identify an association of the VB and certification results. In this case, it would be recommended to analyze the association between the verification teams, within the audit organization and the average results.

Once the variables to be tested are determined, a clear hypothesis and the justification of why they should not be associated is needed. If the hypothesis is fragile or easily disputed, the entire analysis can fail on its purpose, regardless of the robustness of the applied technique.

The statistical analysis used for this case study, the t-test, like any other, has its limitations. Its use to compare average deviations is only adequate if there are enough observations to allow a proper comparison, as well as will only function for homoscedastic variance, which means the variance of the samples is similar. If the data do not fall into those principles, a change in the technique may be needed.

Accordingly, a discussion over outliers' exclusion, or not, is needed.

Assuming t-test adequacy, each p-value under 0.05 will indicate an association of variables. The quantitative result of such tests should support the type of questions that will be made to the stakeholders, preferably chosen among the program experts. It is important to know if the results were expected or not and how they impact the program integrity based on the stakeholder's perception. Viable solutions should also be provided by those experts to drive the recommendations for improvement that will be made. Appendix 2 questionnaire can be used as a sample for a structured questionnaire.

By having quantitative results analyzed and shared with stakeholders, adjustments of rules and procedures can be developed. It should consider changes in the regulation or procedures and acknowledge that those changes should work to incentivize better practices without increasing the efforts, instead of bringing more complexity to the program integrity.

Finally, it is quite important to make a follow-up round of analysis after the propositions were implemented. If the undesired associations are eliminated, then the framework is deemed functional. If the associations remain, then a deeper assessment of the causes of the statistical association should be made.

This conceptual framework can be applied to any certification program for avoiding GHG emissions which seek to improve quality levels without increasing oversight activities (which is costly and increases workload).

It must be recognized that the audit techniques and principles are somehow old, and sometimes fail, not solely due to bad intentions, but because of human mistakes.

New future horizons are opening up based on the appearance of new technologies enabling faults to be minimized and information to be captured at an unprecedented level of capillarity and security. Blockchain technologies, together with the correct application of incentives for agents to provide high-quality trustable and complete information, have the potential to eliminate the faults and transform the business of certifications. Perhaps this will be the topic of a further dissertation.

Appendix 1

Outlier Analysis

An outlier is a number above the Upper-bound or below the lower-bound, given that:

Q1 = 1st Quartile

Q3 = 3rd Quartile

IQR = Interquartile Range = (Q3-Q1)

U Bound = Upper-bound = Q3 + 1.5 x IQR

L Bound = Lower-bound = Q1 - 1.5 x IQR

Table 24. Outlier assessment.

Outliers for Sugarcane ethanol (E1GC) route	U-bound outliers	L-bound outliers	Assessment
NEEA Hydrous (N=223)	0	0	No outliers were detected.
E% (N=223)	0	18	The variation in the eligibility fraction is very large and the distribution is not normal (between 0 and 1, but concentrated around 0,9), making it difficult to analyze outliers that assume a normal distribution. The t-test did not detect an association between E% and a verifier that could pose a risk to the program's integrity. Thus, the difficult statistical treatment and the lack of interference from outliers in the result of the analysis means there is no need for special treatment. All were maintained in the sampling. (See the

			AVG t-tests (Cane Ethanol) & AVG t-tests (Cane Ethanol tabs)
Timeline (N=223)	15	0	10 of the 15 observations occurred in certifications started in 2019 (the oldest). The t-test without excluding outliers shows that certification took longer at the start of the program. If the outliers are removed, the conclusion is the opposite. certification at the beginning of the program was faster. Thus, the existence of the outliers forms part of the statement that the program's certification became quicker.
Diesel and fertilizers	--	--	It does not make sense to remove the outliers. They have provided relevant quantitative information and the whole point of the discussion is to highlight that there are marked differences. By removing the outliers, this perspective is lost. (Bottini, unpublished data)

Appendix 2

Interview Questionnaire

Identification:

Your name will only be mentioned in the study acknowledgments if authorized:

☐ I authorize my name to be mentioned in the thesis.

☐ I **DO NOT** authorize my name to be mentioned in the thesis.

Name: (Identification is mandatory)

Role / Institution:

☐ Consultant

☐ Auditor – Verification Body

☐ Sector association / unions

☐ Regulation. (ANP, MME, Other)

☐ Other:

Context:

This study found relevant empirical associations among variables that should, in principle, not be associated. I would like to have your opinion about those findings:

1. The average eligibility fraction (E%) of sugarcane ethanol plants (E1GC) is 86.49%, whilst the Biodiesel eligibility fraction is 45.29%. The difference is statistically significant (p-value<0.0001)

1.1 Did you know that?

☐ Yes ☐ No

1.2 In your opinion, why does such association (E% and biofuel route), occur?

1.3 What statement better represents your understanding of this fact:

☐ Association is **expected** and does not pose a risk to the program's integrity.

☐ Association is **unexpected** and poses a low risk to the program's integrity.

☐ Association is **unexpected** and poses a relevant risk to the program.

1.4 (if the above answer is "unexpected", what would you do to mitigate, or correct those variables association?

2. One of the 3 largest Verification Bodies, delivers an average NEEA above the average of other Verification Bodies. The difference is statistically significant (p-value=0.0425).

2.1 Did you know that?

☐ Yes ☐ No

2.2 In your opinion, why does the association (NEEA average and Verification Body), occur?

2.3 What statement better represents your understanding of this fact:

☐ Association is **expected** and does not pose a risk to the program's integrity.

☐ Association is **unexpected** and poses a low risk to the program's integrity.

☐ Association is **unexpected** and poses a relevant risk to the program.

2.4 (If the above answer is "unexpected", what would you do to mitigate, or correct those variables association?

3. The average delay for the issuance of the first 35 certificates, from public consultation to certification publication, was 118 days. The last 35 issued certificates had an average delay of 90 days. The difference is statistically significant (p-value<0.02525).

3.1 Did you know that?

☐ Yes ☐ No

3.2 In your opinion, why does such association (age of submission and certification timeline), occur?

3.3 What statement better represents your understanding of this fact:

☐ Association is **expected** and does not pose a risk to the program's integrity.

☐ Association is **unexpected** and poses a low risk to the program's integrity.

☐ Association is **unexpected** and poses a relevant risk to the program.

3.4 (If the above answer is “unexpected”), what would you do to mitigate, or correct those variables association?

4. Fertilizers inputs can be made at different spots of the Renovacalc. Nitrate (N) fertilizers are particularly important for greenhouse gases emissions. Inputting fertilizers (N) at specific fields, such as (Ammonia, MAP, Urea, etc.) results in a 6% higher GHG emission when compared to its input on the general for (N).

There is one VB, among the 3 largest, that only accepted 9% of N fertilizers reports as others, whilst the other 2 largest VB accepted about 20% of N fertilizers as others (N). The difference is statistically significant (p-value<0.0366)

4.1 Did you know that?

☐ Yes ☐ No

4.2 In your opinion, why do such association (verification body and acceptance of Nitrate fertilizers input as other), occur?

4.3 What statement better represents your understanding of this fact:

☐ Association is **expected** and does not pose a risk to the program’s integrity.

☐ Association is **unexpected** and poses a low risk to the program’s integrity.

☐ Association is **unexpected** and poses a relevant risk to the program.

4.4 (if the above answer is “unexpected”, what would you do to mitigate, or correct those variables association?

5. Please provide any comment you understand to be relevant.

References

Agro Insper (2021). Elegibildade e o Renovabio – Apresentação Final. [Renovabio and Eligibility – Final Presentation] PowerPoint slide 12.

Aprosoja Brasil (2021). A Soja [the soybean], retrieved in 10 04 2021 from: https://aprosojabrasil.com.br/a-soja/

B3 (2020). B3 stock exchange CBIO negotiated volume. Retrieved in 11 03, 2020 from: http://www.b3.com.br/pt_br/market-data-e-indices/servicos-de-dados/market data/historico/renda-fixa/

BiodieselBR (2021). Erro aumenta nota ambiental do biodiesel da Bunge no RenovaBio. [Mistake increases NEEA from Bunge biodiesel plant]. Retrieved in 03 12, 2021 from: https://www.biodieselbr.com/noticias/regulacao/rbio/erro-aumenta-nota-ambiental-do-biodiesel-da-bunge-no-renovabio-100321

Blandford, D., & Hassapoyannes, K. (2018). The Role of Agriculture in Global GHG Mitigation. OECD Food, Agriculture and Fisheries Papers, *No. 112. Paris: OECD Publishing*

Brazilian Sugarcane (2021). Sugarcane, Retrieved in 10 04 2021 from: https://brazilianfarmers.com/sugarcane/

Burke, M., Davis, W.M. & Diffenbaugh, N.S. (2018). Large potential reduction in economic damages under UN mitigation targets. *Nature* **557,** 549–553 (2018). https://doi.org/10.1038/s41586-018-0071-9

California Air Resources Board (2010). Low Carbon Fuel Standard Regulation: "Title 17.Public Health, Division 3. Air Resources, Chapter 1. Air Resources Board, Subchapter 10. Climate Change, Subchapter 10. Climate Change, Article 4. Regulations to Achieve Greenhouse Gas Emission Reductions, Subarticle 7. Low Carbon Fuel Standard, sections 95480 to 95503. Last updated in May 27, 2020.

Chassagneux, J., Muûls, M., & Chotai, H. (2017). A Forward-Backward SDEs Approach to Pricing in Carbon Markets (Mathematics of planet Earth). *Springer International Publishing.*

EMBRAPA: Brazilian Agricultural Research Corporation (2017). Evento discute a calculadora da intensidade de carbono de biocombustíveis do RenovaBio em SP. Retrieved in 11, 22, 2020 from: https://www.embrapa.br/busca-de-noticias/-

/noticia/28888826/evento-discute-a-calculadora-da-intensidade-de-carbono-de-biocombustiveis-do-renovabio-em-sp

Departamento de Biocombustíveis/SPG/MME – Ministry of Mining and Energy (2020): 8ª Reunião ordinária do Comitê RenovaBio conduzida remotamente em 22 de maio de 2020 [8th Ordinary meeting of Renovabio committee held remotely in in 05 22, 2020].

Gaudarde, G (2020). Brasilcom entra com nova ação judicial para reduzir metas do Renovabio [Brasilcom files new lawsuit to reduce Renovabio targets]. EPBR, Retrieved in 03 11, 2020 from: https://epbr.com.br/brasilcom-vai-mover-nova-acao-judicial-para-reduzir-metas-do-renovabio/

Glen, S. (2021). T-Test (Student's T-Test): Definition and Examples. Retrieved in 03 14 2021 https://www.statisticshowto.com/probability-and-statistics/t-test/

Interamerican Development Bank (2016). Carbon pricing instruments: final presentation, 4. Brasília, DF, Brazil.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved 11 28, 2020, from http://www.ipcc.ch/report/ar5/wg1

IPCC. (2014). AR 5 - Summary for Policy Makers. Retrieved 06 23, 2019, from https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf

Kosnik, L. (2018). Cap-and-trade versus carbon taxes: Which market mechanism gets the most attention? *Climatic Change,151*, 605-618

Krosnick, J. (1999). Survey Research. *Annu. Rev. Psychol. 1999. 50:537-67*

Krosnick, J., (2009). Question and Questionnaire Design. *Handbook of Survey Research (2nd Edition). San Diego, Stanford University CA: Elsevier*

Liverani, A. (2009). Climate Change and Individual Behavior Considerations for Policy. The World Bank Development Economics Office of the Senior Vice President and Chief Economist, *World Bank* September 2009

Ministério de Minas e Energia & National Oil Agency (2018). Resolution # 758 (227 ed.). Rio de Janeiro. Retrieved in 09 24, 2020 from: https://www.gov.br/anp/pt-br/assuntos/producao-e-fornecimento-de-biocombustiveis/renovabio/renovabio/legislacao-do-renovabio

Mityakov, S., & Rühl, C. (2009). The Stern Review on climate change: Inconvenient sensitivities. *Energy & Environment, 20(5)*,779-798.

Moon, B. K. (2019). Secretary-General Statement. Retrieved 06 23, 2019, from: https://www.un.org/sg/en/content/sg/statement/2018-09-10/secretary-generals-remarks-climate-change-delivered

National Oil, Gas and Biofuel Agency (2020a). ANP Renovabio Certified producers spreadsheet. Retrieved 12 31, 2020 from http://www.anp.gov.br/producao-de-biocombustiveis/renovabio/certificados-producao-importacao-eficiente

National Oil, Gas and Biofuel Agency (2020b). Formulário D: certificado de produção e importação eficiente de biocombustíveis [Form D: certificate of production and efficient import of biofuels]. (02 ed.) Rio de Janeiro.

National Oil, Gas and Biofuel Agency (2020c). Renovabio - Public Consultation. Retrieved November 2020, from: http://www.anp.gov.br/producao-de-biocombustiveis/renovabio/consulta-publica-certificacao-producao

National Oil, Gas and Biofuel Agency (2020d). Technical Inform #02: Orientações Gerais: Procedimentos para Certificação da Produção ou Importação Eficiente de Biocombustíveis [General Guidelines: Procedures for Certification of Production or Efficient Import of Biofuels]. (03 ed.) Rio de Janeiro

National Oil, Gas and Biofuel Agency (2020e). Technical Inform #03: Orientações para preenchimento da RenovaCalc [Guidelines for populating data in RenovaCalc] (01 ed.). *Rio de Janeiro*

National Oil, Gas and Biofuel Agency (2020f). Planilha RenovaCalc V.6.1 - Ferramenta de cálculo da intensidade de carbono de biocombustíveis - atualizado em 27/01/2020. [Spreadsheet RenovaCalc V.6.1 - Tool for calculating the carbon intensity of biofuels - updated in 01 27, 2020]. Retrieved in 04 22, 2020 from: https://www.gov.br/anp/pt-br/assuntos/producao-e-fornecimento-de-biocombustiveis/renovabio/renovabio/renovacalc

National Oil, Gas and Biofuel Agency (2020g). Planilhas de Produtores V.6.1. [Producer Spreadsheets V.6.1]. Retrieved in 04 22, 2020 from: https://www.gov.br/anp/pt-br/assuntos/producao-e-fornecimento-de-biocombustiveis/renovabio/renovabio/renovacalc

National Oil, Gas and Biofuel Agency (2020h). Credenciamento de Verification Body [Inpecting Firms Accreditation]. Retrieved in 05 03, 2020 from: https://www.gov.br/anp/pt-br/assuntos/producao-e-fornecimento-de-biocombustiveis/renovabio/renovabio/credenciamento-de-firma-inspetora

National Oil, Gas and Biofuel Agency (2020i). Lições aprendidas e melhorias - Processos de certificação e renovação da certificação [Lessons learned and improvement on certification and re-certification processes]. *Coordenação e Gestão do Renovabio* 4 13, 2021.

National Oil, Gas and Biofuel Agency (2020j). Sanções Aplicadas às Firmas Inspetoras [Sanctions applied to Verification Bodies]. Retrieved in 05 23, 2021 from: https://www.gov.br/anp/pt-br/assuntos/renovabio/renovabio/acoes-de-fiscalizacao-e-sancoes-administrativas-aplicadas-as-firmas-inspetoras

Nordhaus, W. (2007). Economics. Critical assumptions in the Stern Review on climate change. *Science, 317(5835), 201-202.*

Observatório da Cana (2018). Área cultivada com cana-de-açúcar [Sugarcane planted area]. Retrieved in 03 04, 2021 from: https://observatoriodacana.com.br/historico-de-area-bge.php?idMn=33&tipoHistorico=5

Olhoff, A. (2018). Emissions Gap Report. Bonn: *United Nations Environmental Protection Agency*.

Reuters (2020). AgRural consultant forecasts larger soybean area planted in Brazil and record harvest potential. CE Noticias Financeiras. Retrieved in 03 04, 2021 from: https://hollis.harvard.edu/primo-explore/search?query=any,contains,soy%20planted%20area%20in%20brazil&tab=everything&search_scope=everything&vid=HVD2&lang=en_US&offset=0

República do Brasil (2015). Intended National Determined Commitment. Retrieved from http://www.itamaraty.gov.br/images/ed_desenvsust/BRASIL-iNDC-portugues.pdf

República do Brasil (2017). Política Nacional de Biocombustíveis - LEI Nº 13.576 [National Biofuels Policy - Law #13,576]. Brasília, Brasil. Retrieved 11 01, 2020, from: http://www.planalto.gov.br/ccivil_03/_Ato2015-2018/2017/Lei/L13576.htm

Santander Bank & Green Domus (2021). Análise de Situação – Renovabio. [Situation Analysis – Renovabio].

Stern, N. (2008). The economics of climate change. *American Economic Review, Vol.98 (2), p.1-37*

Spiegel, M. R. (1993). Estatística [Statistics]. *Mc Graw Hill 3rd edition p.p 218-221*

Sullivan, L. (n.d.). Hypothesis testing for means & proportions: Retrieved 10 08, 2020, from http://sphweb.bumc.bu.edu/otlt/MPH-Modules/BS/BS704_HypothesisTest-Means-Proportions/BS704_HypothesisTest-Means-Proportions_print.html

UN Environmental Programme (2019). Bridging the gap: enhancing mitigation ambition and action at G20 level and globally. Pre-release version of a chapter in the forthcoming *UNEP Emissions Gap Report 2019*.

UNFCCC. (2010). Conference of the Parties. *FCCC/CP/2010/7/Add.1 (p.3)*. Cancun: *United Nations.*

United Nations (1993). Report of the United Nations Conference of Environment and Development. The Rio Earth Summit. (pp. 112 - 114; 238-240; 263-268). New York: United Nations. Retrieved 11 28, 2020, from: http://publications.gc.ca/Collection- R/LoPBdP/BP/bp317-e.htm

United Nations (2015). Paris Agreement. Retrieved in 03 14 2017 from: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

United Nations Environmental Programme (2018). Terminal Evaluation of the UN Environment / GEF Project: Mitigation Options of GHG Emissions in Key Sectors in Brazil. Retrieved 11 28, 2020, from: https://wedocs.unep.org/handle/20.500.11822/26290

United Nations General Assembly. (1994). United Nations Framework Convention on Climate Change: resolution / adopted by the General Assembly. *UN General Assembly.*

World Bank (2019a). PMR Project Implementation Status Report. Retrieved 10 15, 2020, from: https://www.thepmr.org/system/files/documents/Brazil%20PMR%20Project%20Implementation%20Status%20Report%202019_PA21.pdf

World Bank (2019b). World Population Growth: How has world population growth changed over time? Retrieved 11 30, 2020 from https://ourworldindata.org/world-population-growth#how-has-world-population-growth-changed-over-time

World Bank (2021a). Poverty and inequality Retrieved 03 04, 2021 from https://datatopics.worldbank.org/world-development-indicators/themes/poverty-and-inequality.html

World Bank (2021b). DataBank – World Development Indicators, last updated in 02 17, 2021, Database Retrieved in 03 04, 2021 from: https://databank.worldbank.org/reports.aspx?source=2&type=metadata&series=SI.POV.GINI#

Yohe, G. (2015). Climate change economics. *International Encyclopedia of the Social and Behavioral Sciences, Elsevier* 2nd Edition, 860-864