REPORT ON THE TECHNOLOGY NEEDS ASSESSMENT FOR THE IMPLEMENTATION OF CLIMATE ACTION PLANS IN BRAZIL: MITIGATION

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Secretariat for International Economic Affairs
Ministry of Economy
BRAZIL

MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATIONS

PÁTRIA AMADA BRASIL
GOVERNO FEDERAL

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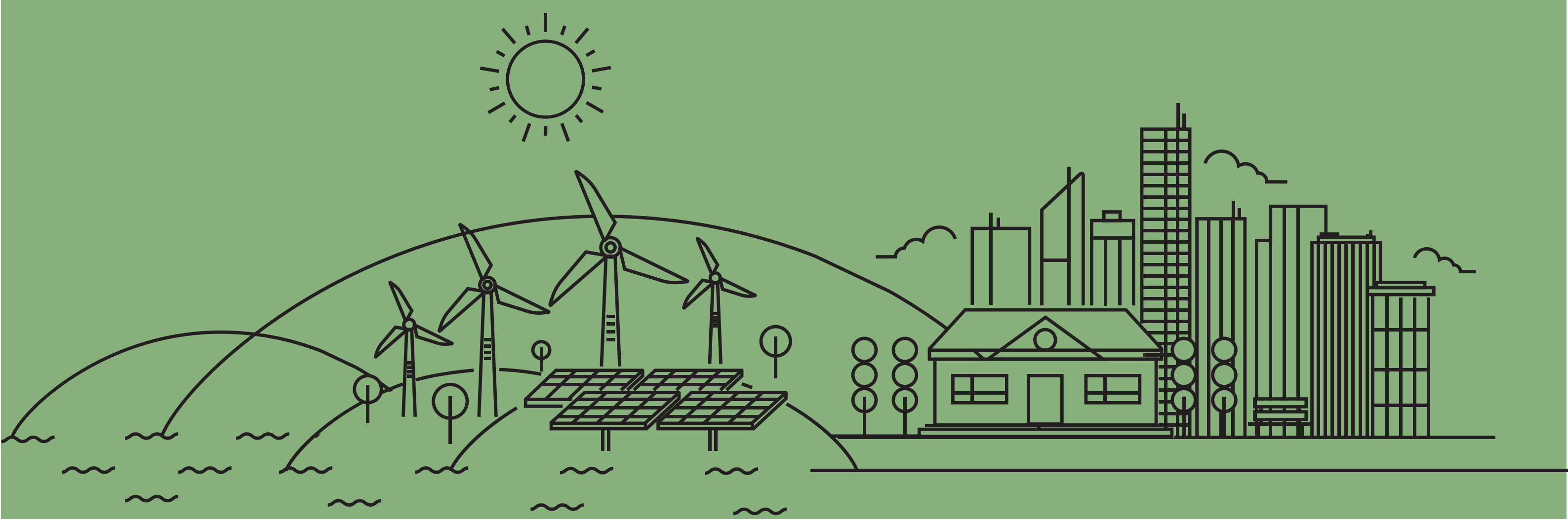

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- Ministério do Desenvolvimento Regional
- Ministério do Meio Ambiente
- Universidade de São Paulo
- Universidade Federal de Minas Gerais
- Universidade Federal do Rio de Janeiro
- World Resources Institute

List of Abbreviations and Acronyms

ABCM – Associação Brasileira do Carvão Mineral / Brazilian Coal Association
ABDI – Agência Brasileira de Desenvolvimento Industrial / Brazilian Industrial Development Agency
ABSOLAR – Associação Brasileira da Energia Solar Fotovoltaica / Brazilian Photovoltaic Solar Energy Association
Afolu – Agriculture, forestry and other land use
AHP – Analytic Hierarchy Process
Aneel – Agência Nacional de Energia Elétrica / National Electric Energy Agency
ANP – Agência Nacional de Petróleo, Gás Natural e Biocombustíveis / National Petroleum, Natural Gas and Biofuels Agency
PE – Precision agriculture
APROBIO – Associação dos Produtores de Biocombustíveis / Association of Biofuel Producers
ATJ – Alcohol-to-jet
BEVs – Battery electric vehicles
BNDES – Banco Nacional de Desenvolvimento Econômico e Social / National Bank for Economic and Social Development
Câmara I4.0 – Câmara Brasileira da Indústria 4.0 / Brazilian Chamber of Industry 4.0
Capex – Capital expenditure
CBAPD – Comissão Brasileira de Agricultura de Precisão e Digital / Brazilian Commission for Precision and Digital Agriculture
CCS – Carbon capture and storage
Celpe – Companhia Energética de Pernambuco / Pernambuco Energy Company
Cemig – Companhia Energética de Minas Gerais / Energy Company of Minas Gerais
Cenpes – Centro de Pesquisas Leopoldo Américo Miguez de Mello / Leopoldo Américo Miguez de Mello Research Center
Cepel – Centro de Pesquisas de Energia Elétrica / Electric Energy Research Center
Cetesb – Companhia Ambiental do Estado de São Paulo / Environmental Company of the State of São Paulo
CGCL/MCTI – MCTI's General Coordination on Climate Science and Sustainability
CGEE – Centro de Gestão e Estudos Estratégicos / Management and Strategic Studies Center
CGTL – CompactGTL
CI – Comissão de Serviços de Infraestrutura do Senado / Comissão de Serviços de Infraestrutura do Senado
CNT – Confederação Nacional dos Transportes / National Transport Confederation
Copel – Companhia Paranaense de Energia / Paranaense Energy Company
CPqD – Centro de Pesquisa e Desenvolvimento em Telecomunicações / Telecommunications Research and Development Center
CSP – Concentrated solar power
CTBE/CNPEM – Laboratório Nacional de Ciência e Tecnologia do Bioetanol do Centro Nacional de Pesquisa em Energia e Materiais / National Bioethanol Science and Technology Laboratory of the National Research Center for Energy and Materials
CTCL – Centro Tecnológico de Carvão Limpo da Faculdade SATC / Technological Center for Clean Coal of SATC Faculty
CTCN – Climate Technology Centre and Network

CTGAS-ER – Centro de Tecnologia do Gás e Energia Renovável / Renewable Energy and Gas Technology Center
DoD – U.S. Department of Defense
DPC – Drying, Pyrolusis and Cooling
E&P – Oil and gas exploration and production
EESC – Escola de Engenharia de São Carlos / São Carlos School of Engineering
EFCEVs – Ethanol Fuel Cell Electric Vehicle
Embrapa – Empresa Brasileira de Pesquisa Agropecuária / Brazilian Agricultural Research Corporation
Embrapii – Empresa Brasileira de Pesquisa e Inovação Industrial / Brazilian Industrial Research and Innovation Company
ENCTI – Estratégia Nacional de Ciência, Tecnologia e Inovação / National Science, Technology and Innovation Strategy
EPE – Empresa de Pesquisa Energética / Energy Research Company
EQ – Escola de Química da Universidade Federal do Rio de Janeiro / School of Chemistry, Federal University of Rio de Janeiro
ETEs – Estações de tratamento de esgotos / Sewage treatment plants
Fapesp – Fundação de Amparo à Pesquisa do Estado de São Paulo / São Paulo State Research Support Foundation
FCC – Fluid catalytic cracking unitts
Finep – Financiadora de Estudos e Projetos / Financier of Studies and Projects
FPSO – Floating production storage and offloading
GCF – Green Climate Fund
GHG – Greenhouse gases
GEF – Global Environment Facility
GMOs – Genetically modified organisms
GTL – Gas-to-liquids
HGU – Hydrogen generation units
IABr – Instituto Aço Brasil / Brazil Steel Institute
Iata – International Air Transport Association
ICE – Internal combustion engine
ICMS – Imposto sobre Circulação de Mercadorias e Serviços / Tax of Goods and Services
Inpe – Instituto Nacional de Pesquisas Espaciais / National Institute for Space Research
INT – Instituto Nacional de Tecnologia / National Institute of Technology
IOF – Imposto sobre Operações Financeiras / Financial transaction tax
IPAM – Instituto de Pesquisa Ambiental da Amazônia / Amazon Environmental Research Institute
IPI – Imposto sobre Produtos Industrializados / Taxes over industrialized products
IPVA – Imposto sobre a Propriedade de Veículos Automotores / Motor Vehicle Property Tax
Irena – International Renewable Energy Agency
ITA – Instituto Tecnológico da Aeronáutica / Technological Institute of Aeronautics
LaMPaC/UFMG – Laboratório de Materiais e Pilhas a Combustível da UFMG / UFMG Materials and Fuel Cell Laboratory
Lasup/UFRJ – Laboratório de Aplicações de Supercondutores da Coppe/UFRJ / Coppe / UFRJ Superconducting Applications Laboratory

LNG – Gás natural liquefeito / Liquefied natural gas

MAPA – Ministério da Agricultura, Pecuária e Abastecimento / Ministry of Agriculture, Livestock and Supply

MCDA – Multi-criteria Decision Analysis

MCTI – Ministério da Ciência, Tecnologia e Inovações / Ministry of Science, Technology and Innovations

MCTIC – Ministério da Ciência, Tecnologia, Inovações e Comunicações / Ministry of Science, Technology, Innovations and Communications

MDR – Ministério do Desenvolvimento Regional / Ministry of Regional Development

ME – Ministério da Economia / Ministry of Economy

MMA – Ministério do Meio Ambiente / Ministry of Environment

MME – Ministério de Minas e Energia / Ministry of Mines and Energy

Mob-i – Centro de Mobilidade Sustentável / Center for Sustainable Mobility

MSWs – Municipal solid waste

Must – Montante de utilização do sistema de transmissão / Amount of use of the transmission system

Nasa – National Aeronautics and Space Administration

NDC – Nationally Determined Contribution

NDE – National Designated Entity

NPD – National Project Directorate

Opex – Operating expense

OPVs – Organic photovoltaic

PACTI – Plano de Ações em Ciência, Tecnologia e Inovação para o Desenvolvimento Nacional / Science, Technology and Innovation Action Plan for National Development

Padis – Programa de Apoio ao Desenvolvimento Tecnológico da Indústria de Semicondutores e Displays / Support Program for Technological Development of the Semiconductor and Display Industry

PAM/Coppe/UFRJ – Laboratório de Processos de Separação com Membranas e Polímeros do Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa em Engenharia da Universidade Federal do Rio de Janeiro / Laboratory of Separation Processes with Membranes and Polymers of the Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering at the Federal University of Rio de Janeiro

PCMs – Phase change materials

PIS/Cofins – Programa de Integração Social/Contribuição para o Financiamento da Seguridade Social / Social Integration Program / Contribution to Social Security Financing

Planaveg – Plano Nacional de Recuperação da Vegetação Nativa / National Plan for the Recovery of Native Vegetation

Plano ABC – Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura / Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture

PNMC – Política Nacional sobre Mudança do Clima / National Policy on Climate Change

PNPB – Programa Nacional de Produção e Uso do Biodiesel / National Biodiesel Production and Use Program

PPCDAm – Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal / Action Plan for Prevention and Control of Deforestation in the Legal Amazon

PPCerrado –	Plano de Ação para Prevenção e Controle do Desmatamento e das Queimadas no Cerrado / Action Plan for Prevention and Control of Deforestation and Fires in the Cerrado
Proálcool –	Programa Nacional do Álcool / National Alcohol Program
Proconve –	Programa de Controle da Poluição do Ar por Veículos Automotores / Motor Vehicles Air Pollution Control Program
ProGD –	Programa de Desenvolvimento da Geração Distribuída de Energia Elétrica / Distributed Generation of Electric Energy Development Program
Proinfa –	Programa de Incentivo às Fontes Alternativas de Energia Elétrica / Incentive Program for Alternative Sources of Electric Energy
RCGI/USP –	Centro de Pesquisa para Inovação em Gás da Universidade de São Paulo / Research Center for Gas Innovation at the University of São Paulo
RER –	Rural Environmental Registry
Reidi –	Regime Especial de Incentivos para o Desenvolvimento da Infraestrutura / Special Incentive Scheme for Infrastructure Development
RSB –	Roundtable on Sustainable Biomaterials
SC –	Sectoral Chambers (SCs) of the TNA_BRAZIL project
SDG –	Sustainable Development Goals
Senai –	Serviço Nacional de Aprendizagem Industrial / National Industrial Training Service
Sicar –	Sistema Nacional de Cadastro Ambiental Rural / National Rural Environmental Registry System
SIX –	Unidade de Industrialização do Xisto da Petrobras / Petrobras Shale Industrialization Unit
Smile –	Sistema Solar Híbrido com Microturbina para Geração de Eletricidade e Cogeração de Calor na Agroindústria / Hybrid Solar System with Microturbine for Electricity Generation and Heat Cogeneration in the Agribusiness
SOFC –	Solid oxide fuel cell
TAC –	Technical Advisory Committee (TAC) of the TNA_BRAZIL project
TAPs –	Technology Action Plans
TCO –	Total cost of owernship
TNA –	Technology needs assessment
TRL –	Technology Readiness Level
UFJF –	Universidade Federal de Juiz de Fora / Federal University of Juiz de Fora
UFMG –	Universidade Federal de Minas Gerais / Federal University of Minas Gerais
UFOP –	Universidade Federal de Ouro Preto / Federal University of Ouro Preto
UFRJ –	Universidade Federal do Rio de Janeiro / Federal University of Rio de Janeiro
UFRN –	Universidade Federal do Rio Grande do Norte / Federal University of Rio Grande do Norte
UFSC –	Universidade Federal de Santa Catarina / Federal University of Santa Catarina
UnB –	Universidade de Brasília / University of Brasília
UNEP –	United Nations Enviroment Program
UNFCCC –	United Nations Framework Convention on Climate Change
Unica –	União da Indústria de Cana-de-Açúcar / Union of the Sugarcane Industry
Unicamp –	Universidade Estadual de Campinas / Campinas State University
Unifei –	Universidade Federal de Itajubá / Federal University of Itajubá
UREs –	Usinas de recuperação energética / Energy recovery plants
USP –	Universidade de São Paulo / University of São Paulo
WBCSD –	World Business Council for Sustainable Development
WWF –	World Wide Fund for Nature
ZEBs –	Zero energy buildings

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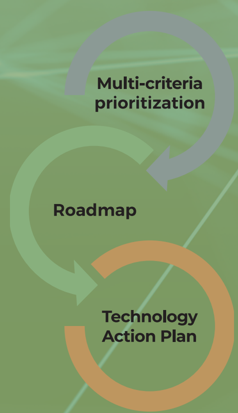
Introduction



Introduction

The "Technology Needs Assessment for the Implementation of Climate Action Plans in Brazil (TNA_BRAZIL)" project aims to strengthen the technical capacity of the Brazilian government through the development of a comprehensive assessment of technology needs for the implementation of climate action plans in Brazil, aimed at providing subsidies for decision making to support the GHG mitigation targets under Brazil's Nationally Determined Contribution (NDC) and the country's strategy for the Green Climate Fund (GCF).

The GCF is one of the financial mechanisms of the United Nations Framework Convention on Climate Change (UNFCCC) intended to channel climate finance to developing countries to support climate change mitigation and adaptation actions. The elaboration of TNA reports is recommended to countries within the scope of the Convention's technology mechanism, of which the MCTI is the Designated National Entity (DNE), responsible for the implementation and operationalization of the mechanism in Brazil.

The TNA_BRAZIL project, executed under the responsibility of the MCTI's General Coordination on Climate Science and Sustainability (CGCL) with support from the United Nations Environment Programme (UNEP) and technical partners, is aligned with several initiatives to promote economic, social and environmental sustainability in Brazil:

- The *Programa País do Brasil* [Brazil Country Program] for the Green Climate Fund (MF, 2018);
- Public notice of the Financier of Studies and Projects (Finep) to support 4.0 technologies in the amount of BRL 50 million (MCTI/FINEP, 2020);
- The Federal Development Strategy for Brazil 2020-2031, with a long-term vision for the stable and coherent performance of federal public administration agencies and entities to promote sustainable GDP *per capita* growth, improved productivity of the Brazilian economy and the conservation and sustainable use of natural resources, focusing on environmental quality as one of the fundamental elements of quality of life, aimed at reconciling the preservation of the environment with economic and social development (BRASIL, 2020);
- The National Strategy for Science, Technology and Innovation 2016-2022 (Encti) to promote sustainable development through the strengthening, expansion, consolidation and integration of the National Science, Technology and Innovation System (MCTIC, 2016);
- The *Regenera Brasil* Initiative, whose objective is to contribute to scientific research, technological development and innovation for the creation of guidelines to promote the recovery of native Brazilian ecosystems (MCTI, 2020);
- Brazilian Commission for Precision and Digital Agriculture (CBPAD), which aims to promote the development of precision and digital agriculture in the country (BRAZIL, 2019);
- Brazilian Chamber of Industry 4.0 (Câmara I4.0), whose objective is to incorporate the federal government public policies to promote industry 4.0, advanced manufacturing and Internet of Things (MCTIC/ME, 2019).

The TNA_BRAZIL project elaboration process has three phases: i) identification and prioritization of technologies for the selected sectors; ii) identification and analysis of value chains, co-benefits and the main barriers to the development and diffusion of the prioritized technologies; and iii) the proposition, based on the previous results, of Technology Action Plans (TAPs) to foster the development and diffusion of the prioritized technologies in each evaluated sector.

The first stage of the TNA_BRAZIL project is the Technology Needs Assessment (TNA) to identify technologies to mitigate emissions that can be developed and/or disseminated in selected sectors by 2030. To this end, three activities were carried out: i) selection of sectors and emission mitigation technologies; ii) elaboration of sustainable development indicators using a multi-criteria analysis (AHP) for scoring the selected technologies and sectors; and iii) ranking and prioritization of the technologies to carry out analyses of value chains, co-benefits, barriers and the preparation of the TAPs. Figure 1 summarizes the steps in the TNA report.

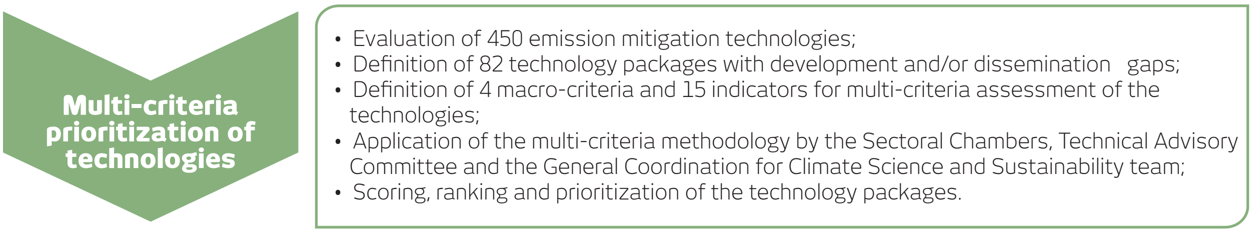


Figure 1 – Elaboration phases of the TNA report

Source: the author.

To identify low carbon technologies, it was initially necessary to define the technological approach. The meaning of "technology" can vary according to the perspective of stakeholders (de CONINCK; SAGAR, 2015), from a strictly technical point of view (engineering and machines) to a broader idea, including behavioral and organizational elements (OLSEN; ENGEN, 2007). To define an adequate scope of the technologies to mitigate GHG emissions, considering the objective of this project, a concept of *stricto sensu* technology was adopted, defined as the integration between machines, devices, tools or artifacts and the knowledge and development necessary to utilize them to their fullest. Based on this definition, the TNA is understood as a process that identifies the initial conditions for removing barriers to the penetration of technologies, whether related to knowledge, experience, diffusion or the stage of technological development. In addition, the idea of exploring a stricter sense of technology derives from the goal to provide the necessary information to develop the TAPs with a view to overcoming the barriers associated with the "valley of death" of technologies[1] (HASELIP et al., 2015).

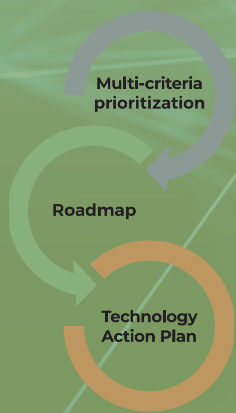
The TNA report has four sections, in addition to the introduction and conclusion. Initially, the institutional arrangements established for the application of the multi-criteria methodology for the analysis of the TNA are reported. Then, the methodological procedures applied for the selection, scoring, ranking and prioritization of emission mitigating technologies are described. The following sections describe these steps and the definition of the 12 prioritized technologies for the elaboration of the TAPs, which consider the national scenario, barriers and potential co-benefits from the adoption of these technologies by 2030.

It should be noted that the group of prioritized technologies resulted exclusively from the physical-financial schedule, as determined by the National Project Directorate (NPD) for the preparation of the action plans. All 82 selected technologies are a priority for Brazil, and efforts should be made to implement them to the fullest extent to maximize the potential co-benefits.

[1] The "valley of death" comprises a set of barriers endemic to most technological innovations. They refer to the unavailability of means, including action and financing plans, to overcome two transitory stages of technological development: first, the scaling of the technology from the proof-of-concept laboratory level, called "Technological Valley of Death"; and subsequently, the demonstration on a commercial scale, referred to as the "Commercialization Valley of Death".

1.

Institutional Arrangements for Engaging Key **Stakeholders in the Technology Needs Assessment Process**



1. INSTITUTIONAL ARRANGEMENTS FOR ENGAGING KEY STAKEHOLDERS IN THE TECHNOLOGY NEEDS ASSESSMENT PROCESS

The TNA process requires the comprehensive and multi-level engagement of key stakeholders. To this end, the project created the Technical Advisory Committee (TAC) and the Sectoral Chambers (SCs) of specialists in the energy, industry, transport, waste, buildings, and agriculture, forestry and other land use (AFOLU) sectors. These chambers were created to support the development of the different stages of the TNA_BRAZIL project.

It was determined that the participation process should take place in workshops, with support documents for decisions made available before to the participants. Figure 2 summarizes the duties of the TAC and SC members in the TNA process, and Appendix I includes the list of permanent members of these stakeholder engagement forums.

TECHNICAL ADVISORY COMMITTEE

Ministries of Science, Technology and Innovation (MCTI); Agriculture, Livestock and Supply (MAPA); Economy (ME); Mines and Energy (MME); Regional Development (MDR); Infrastructure (Minfra); Environment (MMA); Brazil's National Designated Authority for the GCF; Embrapa; Energy Research Company (EPE); National Confederation of Industry (CNI); National Petroleum, Natural Gas and Biofuels Agency (ANP); CAIXA; National Bank for Economic and Social Development (BNDES); Financier of Studies and Projects (Finep).

Tasks:
- Analysis and technical support for the project execution work plan prepared by the National Coordination team;
- Indicate groups of key stakeholders for the sectoral working groups and define their roles and responsibilities in processes;
- Provide technical guidance in all project execution stages;
- Review products (according to area of expertise) elaborated by consultants contracted for the project;
- Promote the extensive participation of key stakeholders in project execution processes; and
- Participate in the ordinary meetings of the Technical Advisory Committee.

SECTORAL CHAMBERS

- Agriculture, forestry and other land uses
- Energy and Industry
- Buildings, Transport and Waste Management

Participants:
Agroicone; Agrosatelite; APROBIO; CNA; IDESAM; INPE; IPAM; MAPBIOMAS; USP; UFRJ; ABAL; ABCM; ABIQUIM; ABIVIDRO; ABSOLAR; CETESB; CGEE; CPFL; FIRJAN; IABr; ICS; INT; Petrobras; Light; SNIC; CETEM; CNT; CNM; FBMC; ICLEI; and invited experts.

Tasks:
- Participate in the application of the multi-criteria analysis to select technologies and priority sectors.
- Contribute subsidies to validate the analysis of value chains, co-benefits, barriers and Technology Action Plans for the prioritized technologies and sectors.

Figure 2 – Members and responsibilities of the TAC and SCs of the TNA_BRAZIL Project

Source: the author.

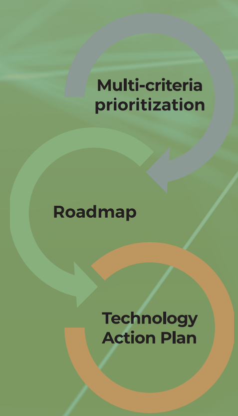
In conjunction with the key project stakeholders, we elaborated multi-criteria forms to evaluate the sustainability indicators for the evaluation of the selected technologies, according to the methodology described in figure 4 and chapter 2 of this document. The NPD conducted five seminars for the application of the multi-criteria methodology, preceded by the submission of technical documentation to establish the objectives of the activity and the concept of the macro-criteria and indicators:

- The first seminar, held on June 28, 2019 in Brasilia/DF, had the participation of MCTI staff and consultants from the project "Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change";
- The second, third and fourth seminars involved the project SCs and took place on July 11 and 12, 2019 in Brasília/DF. They were carried out respecting the multi-sectoral nature of the SCs, which is why three seminars were conducted separately. Initially, multi-criteria seminars were held with stakeholders from the SC for energy and industry, followed by the SC for transport, waste and buildings. The following day, the activity was repeated for specialists in the agriculture, forestry and other land use sector;
- In the fifth seminar on the application of the multi-criteria methodology, which took place on August 9, 2019, the members of the TAC of the TNA_BRAZIL project participated.

It is important to note that the process of applying the methodology occurred individually, with no partial results being released, so as to not bias the position of the stakeholders regarding the attribution of degrees of importance to the macro-criteria and indicators (listed in the next section of this document). Furthermore, the participants did not have access to the list and scoring of the selected technologies, which would imply a sectoral bias in the selection.

2.

Methodology for Selection, **Ranking and Prioritization of Technologies**



2. METHODOLOGY FOR SELECTION, RANKING AND PRIORITIZATION OF TECHNOLOGIES

The decision making process for priority technologies in the context of Brazil depends on criteria and indicators that compare the benefits of implementing the different alternatives to achieve the main objective of the study, which is to reduce national GHG emissions. However, this process is part of a complex scenario that encompasses criteria that contribute differently to the final objective and that can conflict with each other, in addition to involving a number of decision makers from different sectors. Therefore, in order to rank the identified technologies, we used a Multi-criteria Decision Analysis (MCDA) methodology, with an emphasis on the potential co-benefits of these technologies.

One of the most common ways to employ MCDA (chosen for the present study) is the Analytic Hierarchy Process (AHP) (SAATY; VARGAS, 2012). This methodology can be used to solve complex problems that involve different variables. The central idea of the method is to form a hierarchical structure (figure 3), where the first level consists of the final objective, followed by levels of criteria and sub-criteria or indicators, until arriving at the alternatives. Thus, decision makers must rationally and intuitively judge the importance of criteria at a given level only in relation to the immediately higher level. In this way, this hierarchical structuring procedure simplifies the attribution of importance to a series of conflicting criteria, establishing a compromise between them in the end. Consequently, it is possible to select the alternatives that best meet this compromise and contribute to the final objective (SAATY; VARGAS, 2012).

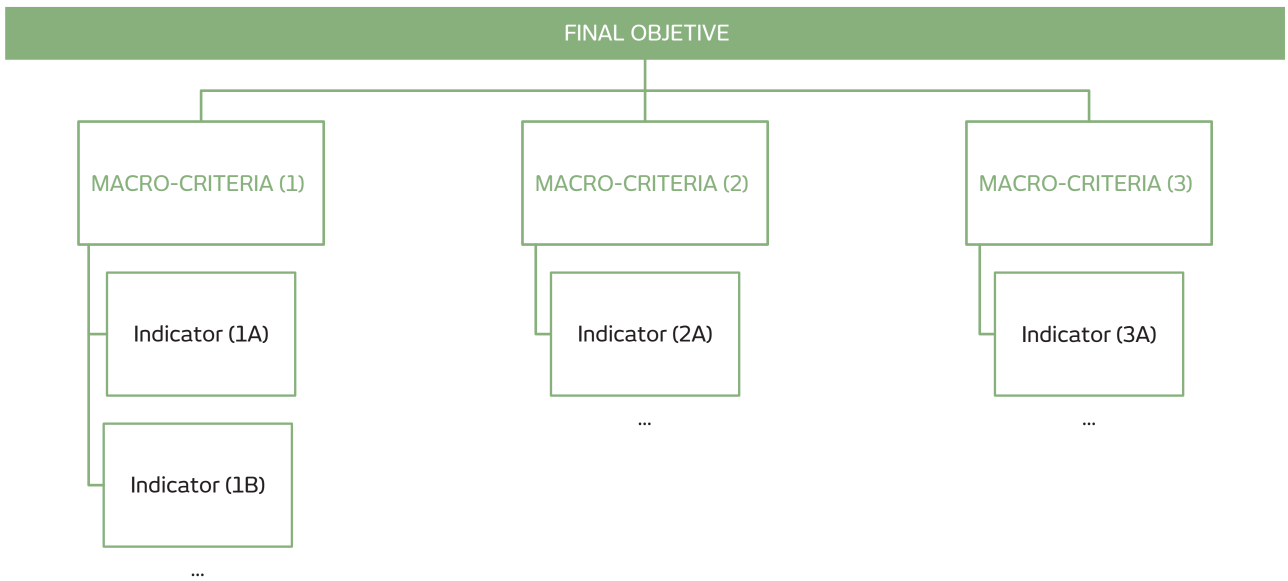


Figure 3 – MCDA hierarchical structure for multi-criteria analysis

Source: the author.

The steps to perform the multi-criteria analysis, based on the AHP methodology, are: i) define the final objective; ii) identify the criteria of each level (in the case of the TNA, macro-criteria and indicators); iii) compare the pairs of macro-criteria and indicators; iv) calculate the relative weight of the macro criteria and indicators; v) assign a score to the alternatives; vi) perform final evaluation of the alternatives; and vii) ranking of alternatives.

The adopted methodological procedure is divided into three main stages: (i) selection of technologies; (ii) multi-criteria analysis; and (iii) ranking and prioritization of technologies. An overview of the methodological procedure is presented in figure 4.

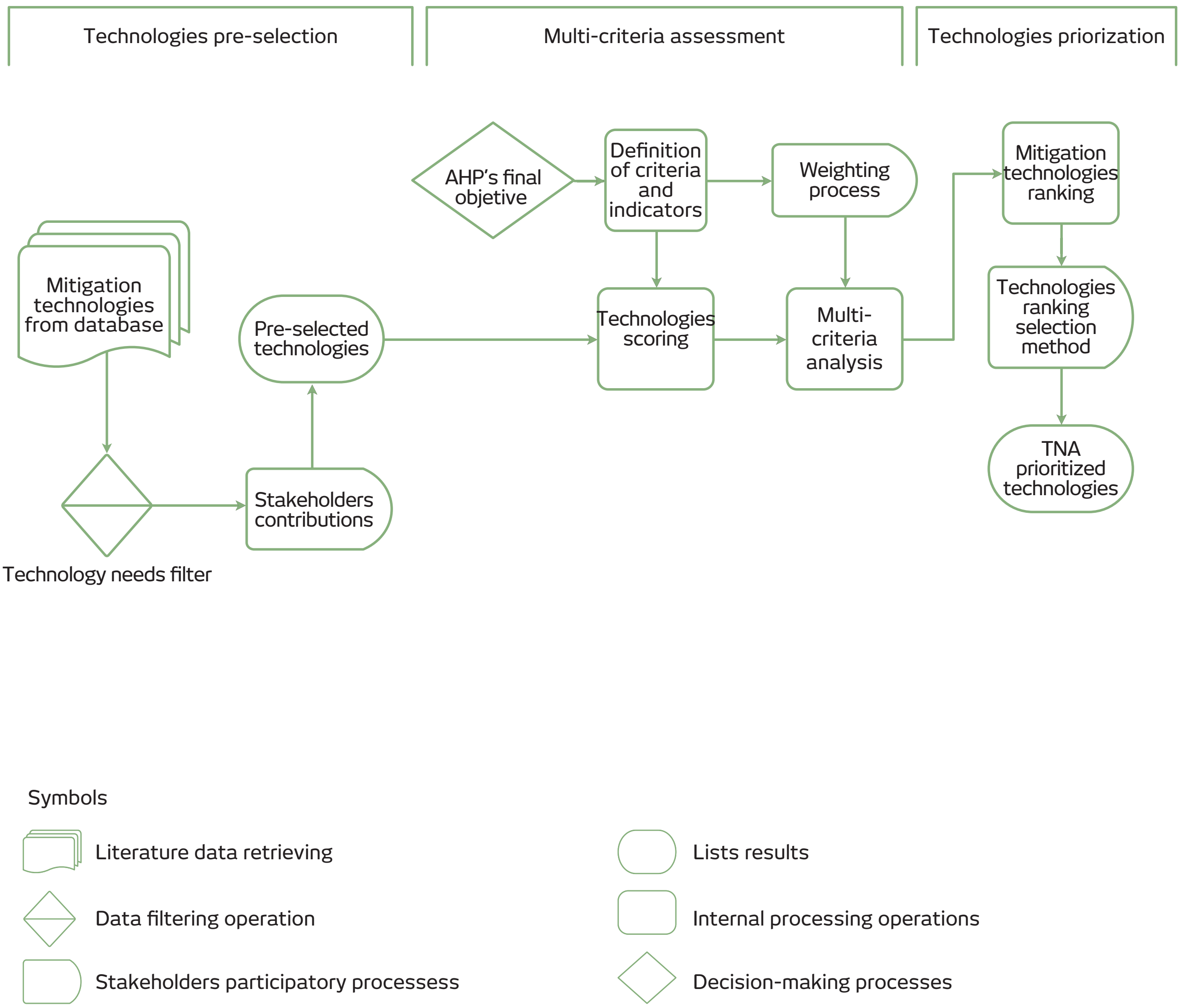


Figure 4 – Flowchart of the initial selection, scoring, ranking and multi-criteria prioritization steps for sectors and technologies to mitigate emissions in the TNA_BRAZIL project

Source: the author.

2.1. Selection of technologies

The first stage of the TNA process consisted of mapping GHG emission mitigation technologies. To do this, we began with publications and the technology database from the project "Mitigation options of greenhouse gas emissions in key sectors in Brazil – MOP" (MCTIC, 2017a ... 2017x; 2018).

The project, an initiative of the Ministry of Science, Technology and Innovations (MCTI) with resources from the Global Environment Facility (GEF) and in partnership with the United Nations Environment Programme, was aimed at providing inputs to assist in decision making for actions to reduce GHG emissions in key sectors of the Brazilian economy: industry, energy, transport, buildings, AFOLU, waste management and other cross-sectoral options. This was an innovative project in that it was the first time that an integrated analysis of the different mitigation options was carried out in Brazil, considering the non-additivity of these options and their consequent economic and social implications.

Starting with the 450 mitigation options mapped in the MOP project, we initially proceeded with the description of the group of technologies that were part of the measures. In view of the technological approach of the TNA_BRAZIL project, it was initially necessary to determine the set of techniques and technologies contained in each of the mitigation options. As an example, the option with the greatest mitigation potential in the AFOLU sector is the reduction of deforestation (MCTIC, 2017w), which needed to be translated into applied technologies to reduce deforestation, such as satellite monitoring, certification systems for deforestation-free chains and validation systems for the Rural Environmental Registry, among others.

Then, it was necessary to identify the low carbon options in the group of technologies that have technological barriers to their widespread diffusion in Brazil. Considering the scope of the TNA_BRAZIL project, this step aimed to gloss over technologies that are commercially available but not applied by the sector due to non-economic barriers. In this case, energy efficiency measures were basically disregarded in the energy, industry and transport sectors that are not widely disseminated due to institutional, cultural, political or training barriers.

Moreover, we disregarded technologies in the MOP project that are widely diffused in the AFOLU sector, such as integrated and no-till production systems, livestock intensification and biological nitrogen fertilization. This diffusion results from the successful adoption of numerous public policy instruments, among which we can highlight the ABC Plan (Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture); the Forest Code; Planaveg (National Plan for the Recovery of Native Vegetation); PNMC (National Policy on Climate Change); PPCDAm (Action Plan for Prevention and Control of Deforestation in the Legal Amazon); and the PPCerrado (Action Plan for Prevention and Control of Deforestation and Fires in the Cerrado) (MMA, 2008; 2017a; 2017b; MAPA, 2012).

Meetings were held with members of Mapa and EMBRAPA to map innovative technologies for the AFOLU sector. From these meetings and documents provided by Embrapa, as well as the Science, Technology and Innovation Action Plan for National Development (PACTI) and the National Science, Technology and Innovation Strategy (2016-2022), we selected 14 technology packages with development and diffusion needs in the sector (MCTIC, 2016). The next section of the document presents the selected emission mitigation technologies.

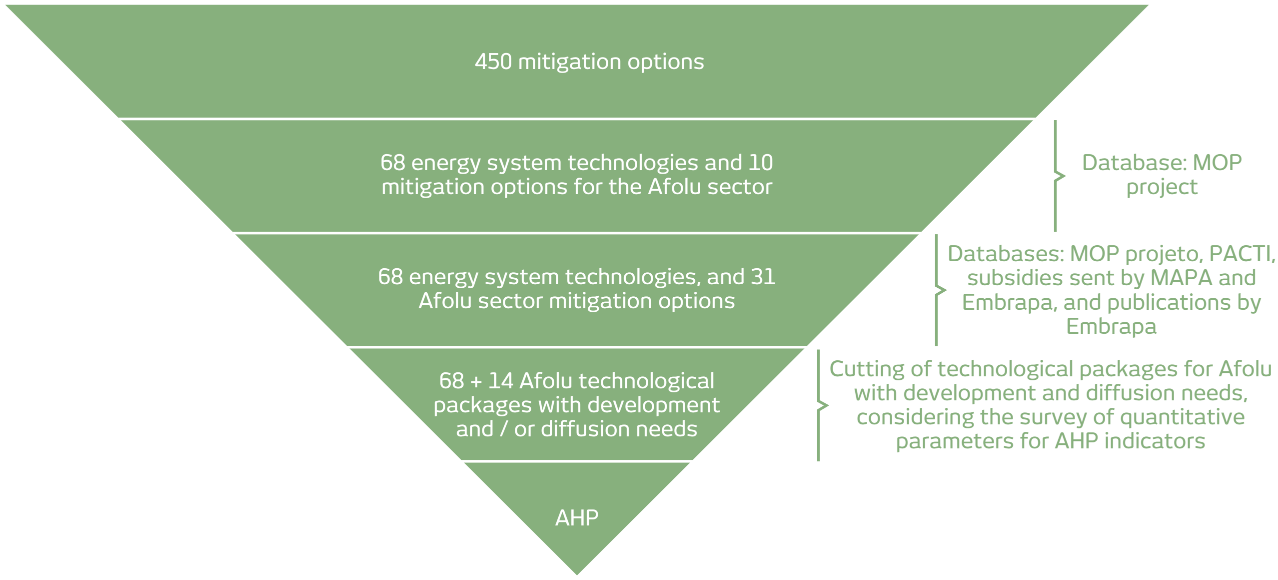


Figure 5 – Selection process for emission mitigation technologies

Source: the author.

2.2. Multi-criteria analysis

A multi-criteria analysis tool was used to prioritize the technologies. Among the available multi-criteria analysis methods, the Analytic Hierarchy Process (AHP) was chosen (HUGHES, 2009; SAATY; VARGAS, 2012; SILVA, 2018). This method consists of creating a hierarchical structure in which the upper level is the final objective of the analysis, which is followed by different levels of macro-criteria and respective indicators. On the lower levels are the alternatives to be prioritized.

Each decision maker involved in the process should judge the relative importance of each criterion at the same level, comparing them in pairs, indicator by indicator. Thus, the AHP method simplifies the establishment of weight for each macro-criterion and indicator according to its relevance to the final objective.

In parallel to this evaluation process, each technology was assessed by the expert authors of this document regarding its performance in each of the established indicators. With the weights of the macro criteria and the indicator scores, a final value was calculated for each technology, allowing for the ranking of the selected emission mitigation technologies.

2.2.1. Definition of criteria and indicators

The first methodological step in the multi-criteria analysis is identifying the final objective, the macro-criteria and the indicators, and organizing them in levels. In this study, the ultimate goal is to select technologies that mitigate GHG emissions and maximize associated co-benefits. For this analysis, the AHP tool was structured on two levels to achieve the final objective, with macro-criteria and indicators. Four macro-criteria and 15 indicators were established. The AHP structure with all the macro-criteria and indicators is shown in Figure 6.

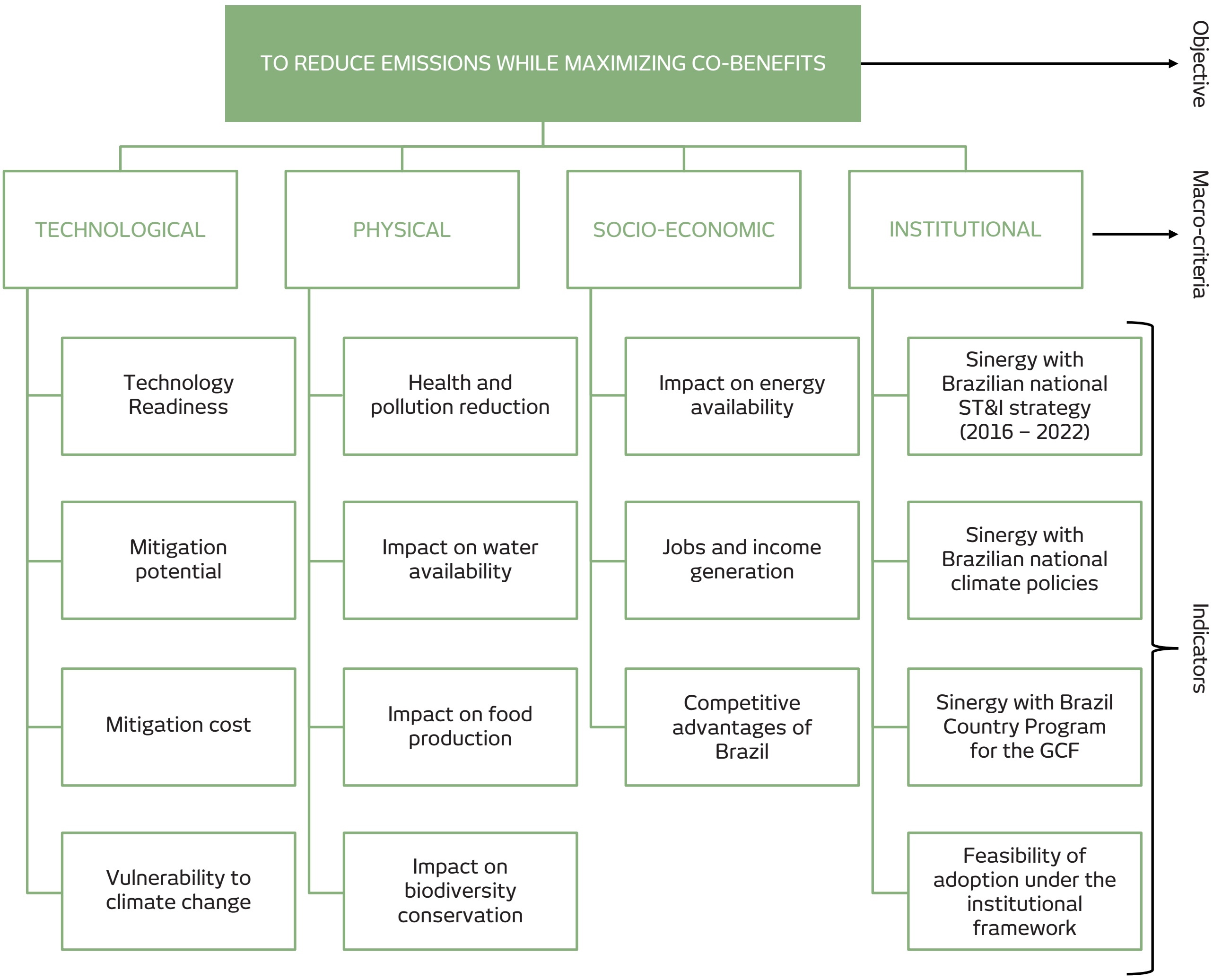


Figure 6 – Structure of the AHP tool applied for the scoring and ranking of emission mitigation technologies

Source: the author.

Table 1 contains a description of the selected macro-criteria and indicators. As can be seen in the description of the indicators, some of them refer to the characteristics of the technologies (for example, the technology readiness level), and others represent national circumstances, such as the country's competitive advantages and institutional framework to implement and use a specific technology. In addition, whenever relevant, the indicators are linked to one or more of the United Nations Sustainable Development Goals (SDGs) (UN, 2020), so that the technology prioritization process can promote sustainable development in the country, aligned with a global agenda vision.

Table 1 – Description of the macro-criteria and indicators used with the AHP tool

MACRO-CRITERIA	DESCRIPTION	INDICATORS	DESCRIPTION
Technological	Contains indicators with a technical perspective, evaluating engineering-level characteristics of the technology	Technology readiness level (TR)	Represents the technology readiness level (TRL) globally
		Mitigation potential (MP)	Emission reduction potential associated with the adoption of the technology
		Mitigation cost (MC)	Technology cost per mitigated CO_2 unit (USD/tCO_2)
		Vulnerability to climate change (VC)	Reflects how technology is exposed to the effects of climate change (for example, rising average temperature, rising sea levels, variability of renewable resources and increased risk of extreme weather events) compared to current practices
Physical	Consists of indicators that reflect the impacts of the technology on the physical environment	Pollution reduction and health benefits / SDG 3 (HP)	Impacts of the technology on the generation of pollutants along the production chain
		Impact on water availability / SDG 6 (WR)	Impacts of the technology on the availability of water resources for society
		Impact on food production / SDG 2 (FP)	Impacts of the technology on agriculture, land use and food security
		Impact on biodiversity conservation / SDG 15 (BD)	Effects of the technology on conservation of biodiversity
Socio-economic	Incorporates indicators that address the effects on social and economic conditions from adopting the technology	Impact on energy availability / SDG 7 (EN)	Impacts of the technology on the amount of energy available to society, efficiency in the use of energy resources, promotion of renewable energy, access to energy and modernization of energy infrastructure
		Job and income generation / SDG 8 and 10 (JI)	Potential impacts of the technology to reduce social inequalities in Brazil, with a focus on generating jobs and income
		Competitive advantages for Brazil (CA)	Assessment of how the technology can benefit from the advantages of production factors and national scientific and technological competence
Institutional	Incorporates indicators that associate the degree of compatibility of technologies with relevant institutional characteristics	Synergy with the National ST&I Strategy (ST)	Relation of the technology within the scope of the Brazilian National Strategy for Science, Technology and Innovation - Encti (2016-2022)
		Synergy with national climate policies (CP)	Alignment of the technology with national climate policies*
		Synergy with the Country Program for the GCF (GF)	Alignment of the technology with the Country Program for the GCF
		Feasibility of adoption under the current institutional framework (IF)	Feasibility of implementing the technology under the current institutional framework, considering barriers (economic, market, institutional, cultural) and gaps in the market

Source: the author.

Note: * Including Brazil's Nationally Determined Contribution under the Paris Agreement (BRASIL, 2015); RenovaBio (MME, 2019); the ABC Plan (Brazilian Plan for Mitigation and Adaptation of the agricultural sectors) (MAPA, 2012); and the National Policy on Climate Change (MMA, 2008).

2.2.2. Scoring of technologies

After defining the macro-criteria and indicators for the multi-criteria evaluation process, the selected technologies were evaluated according to their performance in each indicator.

This step was conducted by the TNA_BRAZIL project technical team using a literature review[2] and, whenever possible, quantitative assessments, as a tool to determine scores from 1 to 5, as shown in Table 2.

Table 2 – Scoring scale according to the classification of the performance of a technology in a given criterion

PERFORMANCE	SCORE
Very poor	1
Poor	2
Average/Neutral	3
Good	4
Very good	5

Source: the author.

For the technology readiness level and emission mitigation potential and costs, a semi-quantitative approach was adopted. Thus, the values of these indicators were normalized to suit the scoring scale shown in Table 2.

The maturity of the technologies was assessed by the Technology Readiness Level (TRL) developed by the National Aeronautics and Space Administration (NASA) and by the U.S. Department of Defense (DoD, 2011). The TRL index is scaled from 1 to 9, with 1 being the lowest technology readiness level and 9 being the highest. For the purposes of this study, the indicator follows the normalization process described in table 3.

Table 3 – Technology readiness level scoring scale

<table>
<tr><th>LEVEL</th><th>DESCRIPTION</th><th>PERFORMANCE</th><th>SCORE</th></tr>
<tr><td>TRL 1</td><td>Research at initial level, with basic principles observed</td><td rowspan="3">Very poor</td><td rowspan="3">1</td></tr>
<tr><td>TRL 2</td><td>Formulation of the technological concept</td></tr>
<tr><td>TRL 3</td><td>Established proof of concept</td></tr>
<tr><td>TRL 4</td><td>Laboratory test prototype elaborated</td><td rowspan="2">Poor</td><td rowspan="2">2</td></tr>
<tr><td>TRL 5</td><td>Laboratory testing / validation of the integrated prototype</td></tr>
<tr><td>TRL 6</td><td>Pilot system verified</td><td rowspan="2">Neutral</td><td rowspan="2">3</td></tr>
<tr><td>TRL 7</td><td>Demonstrated integrated pilot system</td></tr>
<tr><td>TRL 8</td><td>Demonstrated integrated pilot system</td><td>Good</td><td>4</td></tr>
<tr><td>TRL 9</td><td>System widely applied commercially</td><td>Very good</td><td>5</td></tr>
</table>

Source: the author.

[2] The list of references is available at this link.

For the MP indicator, normalization of values follows a limit value based on the country's emission profile. Table 4 shows the intervals for the emission mitigation potential used to define the indicator value for the technologies in this study. The absolute values of the mitigation potential were taken from the results of the MOP project (MCTIC, 2017x).

Table 4 – Scoring scale of the indicator for emission mitigation potential

MITIGATION POTENTIAL RANGE	LIMIT PORTION*	PERFORMANCE	SCORE
< 5,250 Gg CO_2eq	< 2.5%	Very poor	1
5,250-10,500 Gg CO_2eq	2,5%-5%	Poor	2
10,500-15,750 Gg CO_2eq	5%-7.5%	Neutral	3
15,750-21,000 Gg CO_2eq	7.5%-10%	Good	4
> 21,000 Gg CO_2eq	> 10%	Very good	5

Source: the author.

Note: * The limit value in this study is the total emission of the largest emitting sector accounted for in the latest Brazilian Emissions Inventory, with 2016 as the base year (MCTI, 2021a).

For the MC indicator, the cost ranges were aligned with the current carbon pricing scenarios for the short term (up to 2030), following the normalization process shown in table 5. The mitigation costs were also taken from the results of the MOP project (MCTIC, 2017x).

Table 5 – Scoring scale of the indicator for emission mitigation costs

MITIGATION COST RANGE (USD/tCO_2)	JUSTIFICATION	PERFORMANCE	SCORE
> 50	High cost	Very poor	1
25-50	Medium-high cost	Poor	2
10-25	Median cost on the European carbon market	Neutral	3
0-10	Low cost	Good	4
< 0	Negative cost (no regret)	Very good	5

Source: the author.

The other indicators use a qualitative approach and are evaluated based on relative performance. The score with the justifications for technologies and indicators can be seen in Appendix III.

2.2.3. Weighting methodology

The next phase of the multi-criteria method consists of comparing the criteria within each hierarchical level; that is, according to the macro-criteria and indicators. The comparison between pairs of criteria is conducted by the stakeholders using a scale of importance. Thus, in this study, the key stakeholders listed in section 1 and Appendix II were asked to fill in an electronic form, with the following basic question: "In your opinion, for the purpose of reducing emissions with the maximum generation of co-benefits, the "Item A," in relation to the other items listed, is:

Table 6 – General structure of the questionnaire questions given to stakeholders

ITEMS	NOT VERY IMPORTANT	LESS IMPORTANT	EQUALLY IMPORTANT	MORE IMPORTANT	MUCH MORE IMPORTANT
"Item B"	○	○	○	○	○
"Item C"	○	○	○	○	○
"Item D"	○	○	○	○	○

Source: the author.

The questions were asked in five series: four for the evaluation of the indicators for the respective macro-criteria (technological, physical, socioeconomic and institutional) and one for the evaluation of the macro-criteria for the final objective. Then, responses from individual stakeholders were compiled into five comparative matrices, one for each series. Subsequently, the different individual matrices were aggregated according to their average values, generating the five respective final comparison matrices for each series.

In the comparison matrix, the lines and columns represent the analyzed criteria and the intersecting cells (a_{ij}) contain the importance value assigned to the criterion of the line in relation to the column criterion, from 1 to 5. Thus, the diagonal cells receive the neutral value (since a criterion is as important as itself) and the remaining cells receive the reciprocal value of those previously filled in (a_{ij} = 6 - a_{ij}), as shown in table 7.

Table 7 – Pair judgment matrix

	C_1	C_2	...	C_n
C_1	3	a_{12}	...	a_{1n}
C_2	6 - a_{12}	3	...	a_{2n}
...	...	...	3	...
C_n	6 - a_{1n}	6 - a_{2n}	...	3

Source: the author.

The next step in the methodology consists of obtaining the priority vector, or relative weight vector, which indicates the relative importance of the indicators (or macro-criteria) for the respective macro-criterion (or final objective). To do this, a simple way is to first normalize the cells of the matrix (as shown in table 8), dividing each one by the sum of its respective column. Then, each line of the normalized matrix is added. Finally, divide the matrix of a resulting column by the number of criteria.

Table 8 – Steps for calculating the priority vector

STEP 1				STEP 2					STEP 3
	C_1	**…**	**C_n**		**C_1**	**…**	**C_n**		
C_1	3	…	a_{1n}	**C_1**	$C'_{11} = \frac{C_{11}}{\sum_{i=1}^{n} C_{i1}}$	…	$C'_{1n} = \frac{C_{1n}}{\sum_{i=1}^{n} C_{in}}$	$\sum_{j=1}^{n} C'_{1j}$	$C''_{11} = \frac{\sum_{j=1}^{n} C'_{1j}}{n}$
…	…	3	…	**…**	…	…	…	…	…
C_n	$6 - a_{1n}$	…	3	**C_n**	$C'_{n1} = \frac{C_{n1}}{\sum_{i=1}^{n} C_{i1}}$	…	$C'_{nn} = \frac{C_{nn}}{\sum_{i=1}^{n} C_{in}}$	$\sum_{j=1}^{n} C'_{nj}$	$C''_{n1} = \frac{\sum_{j=1}^{n} C'_{nj}}{n}$
	$\sum_{i=1}^{n} C_{i1}$	…	$\sum_{i=1}^{n} C_{in}$						

Source: the author.

Finally, to assess the consistency of the assumptions and judgments regarding the comparison of the criteria, it is necessary to determine the consistency ratio (CR). If its value is greater than 0.1, the matrix is considered inconsistent and should be adjusted. The CR is the ratio between the consistency index (CI) and the random index (RI), as shown in equation (1).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (1)$$

The CI can be calculated by (2), where λmax is the maximum eigenvalue of the judgment matrix and *n* is the number of criteria. The λmax can be obtained using the following steps.

- Multiply the judgment matrix by the priority vector;
- Divide the first component of the resulting vector by the first component of the priority vector, and so on, until you get a new vector;
- Add the components of this new vector and divide by the number of components. The final value obtained is close to the maximum eigenvalue.

$$\mathrm{CI} = \frac{\lambda\text{máx} - \mathrm{n}}{\mathrm{n} - 1} \qquad (2)$$

The random index (RI) is dependent on the number of criteria according to a scale (SAATY; VARGAS, 2012).

As mentioned above, key stakeholders were able to contribute to the weighting process in five workshops. All participants were asked to register their contributions electronically using a form on the Google Forms platform. The replies were compiled in a spreadsheet with the formulas needed to calculate the weight of each indicator and macro-criterion.

2.3. Ranking and prioritization of the technologies

With the application of the methodology to obtain the weights of the macro-criteria and indicators, as well as the scores of the technologies in each indicator, a final value for the technology options is calculated by equation 3, where "FV_t" is the final value of the technology "t"; "$GR_{t,i}$" is the performance level of the technology "t" in indicator "i" (assigned by the technical team); "IN_i" is the weight of the "i" indicator; and "MC_i" is the weight of the macro-criterion referring to indicator "i".

$$FV_t = \sum_{i=1}^{15} (GR_{t,i} * IN_i * MC_i) \quad (3)$$

After calculating the final value for each technology, it is finally possible to rank the technologies. This classification should reflect how the technologies on the list contribute to the ultimate goal in the multi-criteria assessment.

Following this, a discussion was held with the TAC to determine which technologies should be prioritized in the analysis of value chains, co-benefits, barriers[3] and the preparation of the TAPs. The NPD determined that 12 technology packages could be prioritized in view of the physical and financial schedule of the TNA_BRAZIL project.

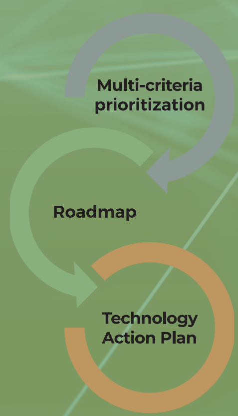
Four methods were proposed to select the ranked priority technologies:

- Ordinal Selection (ORS) – selection based simply on the position of the technology in the ranking, regardless of the sector;
- Selection by Sectoral Equity (SES) – selection based on an equal number of technologies prioritized by sector, following the ranking classification. That is, two technologies for each sector (AFOLU, industry, energy, transport, waste and buildings);
- Selection by Representativeness of Sectoral Emissions (RSE) – the number of technologies chosen for each sector should be proportional to their participation in the country's emissions (MCTI, 2021a), respecting the positioning in the ranking. In this case, six technologies should be chosen for the AFOLU sector, two for the transport sector, two for the industrial sector, and one each for the energy and waste sectors;
- Selection by Sub-sectorial Representation of Emissions (SRE) – the number of technologies selected by sector should be similar to the RSE method, but respect the selection of at least 1 technology for each sub-sector. In this case, the configuration would be five technologies for the AFOLU sector, two for the transport sector, two for the industrial sector, and one each for the energy, waste and buildings sectors.

[3] It was decided to map barriers to the adoption of all the selected priority technologies within the scope of the project, according to Appendix IV.

3.

Selected Emission **Mitigation Technologies**



3. SELECTED EMISSION MITIGATION TECHNOLOGIES

With the procedures described in section 2.1, we identified 82 priority technology packages (described below) to promote sustainable low-carbon development in Brazil by 2030. These packages constitute a data base that will be scored, ranked and prioritized using a multi-criteria methodology (Analytic Hierarchy Process – AHP) in the next section of this TNA document.

3.1. Selected technologies for the industrial sector

With respect to the industrial sector, we identified applicable technologies for the cement, chemical and iron and steel sub-sectors, as well as low-carbon cross-sectoral solutions.

The cement production sector is an industrial sector with high emissions due to its energy-intensity and emissions generated in the thermochemical step of calcinating calcium carbonate in the traditional clinker production process (LORD; JONES; SHARMA, 2017). Thus, mitigation measures for the sector have a significant potential to reduce industrial emissions.

The chemical sector, unlike the other industrial sectors, is characterized by a great diversity of inputs, processes and products. Thus, it is not possible to associate the sector with a single production process, or adopt unique values as representative. With the goal of prioritizing the most energy intensive sectors, the mapped technologies are applicable to production processes in three industrial areas: petrochemical products, fertilizers and chlor-alkali processes.

The iron and steel industry is responsible for a large quantity of GHG emissions from both high energy consumption and the emissions from the chemical reactions in processes. Two steel production classes were considered, based on the energy vector used in the steel manufacturing stage. The first class uses oxygen converters, and the other class produces steel with electric arc furnaces. While the use of oxygen converters is mainly used to produce steel from iron ore, electric arc furnaces are used more for recycling scrap. Thus, the development and/or diffusion of the technologies is applicable in both.

Finally, we considered cross-sectoral technologies that apply to all industrial sub-sectors, which, despite having less impact on the reduction of emissions individually, they offer significant mitigation potential taken as a group. These cross-sectoral technologies, following the same scope of application in the other sub-sectors, are classified according to production efficiency; fuel substitution (alternative fuels); and carbon transport and storage.

Table 9 – Description of technologies that require development and/or diffusion in the industrial sector

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
ADVANCED FLUIDIZED BED COMBUSTION	
Industrial (Cement)	The technology consists of coupling a fluidized bed calcination furnace to a two-stage cooler. The raw material is reduced to a specific particle size in the furnace and is subsequently sintered at a high temperature. Cooling takes place in a fast and slow stage, in order to maximize efficiency in heat recovery and ensure product quality.
GEOPOLYMER CEMENT	
Industrial (Cement)	Geopolymer cements are produced by the reaction between a solid aluminosilicate material and an alkaline solution, known as an alkaline activator. The predominant inputs for the production of geopolymer cement are coal fly ash and granulated blast furnace slag. There is a reduction in emissions compared to Portland cement production as there is no need for limestone calcination (eliminating process emissions) and production is carried out at lower temperatures (less demand for thermal energy).
INNOVATIVE MATERIALS FOR CEMENT	
Industrial (Cement)	The technology seeks to develop cements with a lower carbon footprint by replacing or reducing the clinker content in the composition of cement with alternative raw materials, such as granulated blast furnace slag, fly ash from mineral coal, limestone filler and calcined clays.
HYBRID SOLAR PLANTS	
Industrial (Cement)	This system aims to partially replace the thermal needs in cement production plants with concentrated solar energy using spherical mirrors facing the interior of the calcination furnace. This technology can mitigate emissions in the ratio of avoided fossil fuels to generate thermal energy. However, it does not change process emissions.
CO_2 CAPTURE	
Industrial (Cement)	It consists of capturing CO_2 from flue gas streams using the chemical amine absorption process. It is a mature and widely diffused technology in the chemical industry for the separation of carbon dioxide from gas streams that can also be applied in cement production. CO_2 is absorbed from the effluent gas stream with an amine solution, usually monoethylamine (MEA), at about 50°C. It is then separated from the solution, dried, compressed and stored.
OXYGEN ENRICHMENT SYSTEMS	
Industrial (Cement)	These are systems that use concentrated oxygen as an oxidizer for efficient burning and the formation of flue gas streams with a high concentration of CO_2, facilitating the capture process. As nitrogen is separated from oxygen before combustion, and burning occurs with high efficiency, the flue stream has high-purity carbon dioxide, facilitating the capture process. Almost 100% of the CO_2 in the flue gas can be captured.

continues

continuation

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
CHEMICAL LOOPING	
Industrial (Cement)	This technology separates CO_2 from a gas stream using a metallic oxide that undergoes successive reactions of carbonation and calcination. As the cement manufacturing process already includes a calcium carbonate calcination step, the chemical looping system is quite suitable for the process, making it one of the most promising technologies for capturing CO_2 in cement production.
MEMBRANE SEPARATION	
Industrial (Chemical)	The technology involves the separation of chemical fluids using a fine nanostructured functional barrier, which controls the transfer of mass between two phases due to external forces, the properties of the medium and the intrinsic characteristics of the material. The use of separation membranes is a potential substitute for the traditional energy-intensive techniques currently used, such as liquid-liquid extraction. Membranes can also reduce energy use in the process by working in conjunction with other conventional separation processes, such as distillation.
CATALYTIC CRACKING OF NAPHTHA	
Industrial (Chemical)	Steam cracking of naphtha is currently the main method used globally for the production of ethylene and propylene - a process that requires a large amount of energy. The substitution of the catalytic cracking process can reduce energy consumption in the process, since it operates at a lower temperature and pressure.
USE OF BIOMASS FOR OLEFIN PRODUCTION	
Industrial (Chemical)	The technology uses methanol and ethanol obtained from lignocellulosic raw materials for the production of olefins. Lignocellulosic methanol is produced from the synthesis gas generated in the biomass gasification process. Another way of obtaining olefins, specifically ethylene, is by catalytic dehydration of ethanol, which is produced by fermenting biomass rich in sugar or starch.
USE OF H_2 OBTAINED FROM RENEWABLE SOURCES FOR THE PRODUCTION OF AMMONIA AND METHANOL	
Industrial (Chemical)	The technology uses of solar or wind energy to produce hydrogen by water electrolysis, replacing the stages of greater energy consumption in the production of ammonia and methanol precursors.
CARBON CAPTURE IN AMMONIA PRODUCTION	
Industrial (Chemical)	Ammonia production is the main process for the application of carbon capture in the chemical industry. This process is facilitated by the need to separate CO_2 from ammonia in the process itself, with part of the carbon dioxide obtained being used for the production of urea and the remainder released into the atmosphere. Thus, the little effort required to store the carbon dioxide already captured involves only a greater purification of the gas and adjusting its pressure to meet the requirements of the transport system.

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SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
STEAM REFORMING OF COKE OVEN GAS	
Industrial (Iron and Steel)	This technology uses the hydrocarbon effluents from coke plants to produce CO and H_2 via steam reforming. Thus, it is possible to increase the hydrogen content in the blast furnace and reduce the demand for coke to reduce iron ore. The result is a reduction in CO_2 emissions in the process.
RECOVERY OF RESIDUAL HEAT FROM ELECTRIC ARC FURNACES USING THE ORGANIC RANKINE CYCLE	
Industrial (Iron and Steel)	The technology uses exhaust gases from the electric arc furnace to generate energy with the application of an Organic Rankine Cycle in a process that recovers the residual heat from the electric arc furnace.
APPLICATION OF THE SIDERWIN PROCESS	
Industrial (Iron and Steel)	The SIDERWIN process consists of the electrolysis of iron oxide for the production of mild steel. Its mitigating potential is intrinsically associated with the emission factor of the electricity used.
APPLICATION OF DRYING, PYROLYSIS AND COOLING (DPC) TECHNOLOGY IN CHARCOAL PRODUCTION	
Industrial (Iron and Steel)	DPC technology can be used in three stages: i) heating wood to reduce moisture content to below 10% and release the volatile compounds in the biomass structure; ii) pyrolysis reaction in the material, transforming it into charcoal; and iii) cooling of the material. The energy demand for converting wood to charcoal is met by burning the gases generated in the process itself. The technology provides higher yields compared to the traditional process, in addition to improving the homogeneity and quality of the product.
APPLICATION OF ONDATEC TECHNOLOGY IN CHARCOAL PRODUCTION	
Industrial (Iron and Steel)	Using microwave heating, Ondatec technology involves a horizontal metallic oven with a conveyor belt through which wood passes continuously, receiving energy from the microwaves for pyrolysis. A modern control system monitors the quality of the product, varying the speed of the conveyor and the power level according to the desired chemical parameters for the final product.
BLAST FURNACE GAS COLLECTION AND REFORMING USING THE IGAR PROCESS	
Industrial (Iron and Steel)	The technology uses a plasma torch and a reactor to heat and reform the top gases in the blast furnace to produce hydrogen gas. Re-injecting it into the blast furnace reduces the consumption of coke in the process.
APPLICATION OF THE HISARNA PROCESS FOR FUSION REDUCTION	
Industrial (Iron and Steel)	A fusion reduction process that combines a fusion chamber and a Cyclone Converter Furnace to eliminate the use of coke and sinter. As it operates with pure oxygen, the exhaust gas stream contains a high concentration of CO_2, in a ratio that is almost sufficient to be sent directly to storage.

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SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
INDUSTRY 4.0	
Industrial (Cross-sectoral)	Industry 4.0 is characterized by the development and application of new technologies that integrate the physical and digital worlds to make production chains more efficient, thus reducing energy consumption. These technologies can include Internet of Things (IoT), Big Data, Artificial Intelligence, 3D printing and cloud computing.
USE OF RENEWABLE SOURCES IN INDUSTRIAL PROCESSES	
Industrial (Cross-sectoral)	The substitution of fossil fuels with renewable alternatives in industrial processes is an important measure to mitigate GHG emissions. For the production of thermal energy, the use of biomass or solar heating can be adopted. For electricity, solar, wind or thermoelectric energy from biomass can be used. Other options include the use of biogas as fuel and the installation of solar heaters for heating water.
TRANSPORT OF CO_2	
Industrial (Cross-sectoral)	After capture, CO_2 can be transported for geological storage or commercial use by pipeline, waterway or road. For pipeline transport, CO_2 must be dehydrated and then compressed under high pressure until it reaches high density (supercritical state). An alternative to pipelines for continental transport is road transport, where carbon dioxide is transported in a liquefied state by trucks. Finally, CO_2 in a liquefied state can also be transported by ship.
STORAGE OF CO_2	
Industrial (Cross-sectoral)	CO_2 can be stored in oil and gas reservoirs with low recovery rates, layers of coal, deep saline aquifers and salt caves, where the gas is stored in the form of carbonates from the mineral carbonation process. In addition to geological reservoirs, carbon dioxide can also be injected directly into the oceans.

Source: the author.

3.2. Selected technologies for the energy sector

We divided the energy sector into the following sub-sectors to assess emission mitigation technologies with barriers to diffusion and development: i) oil and natural gas exploration and production (E&P); ii) oil refining; iii) generation, transmission and distribution of electricity; and iv) production of advanced biofuels.

The E&P segment of oil and natural gas involves the stages of prospecting, drilling, evaluation and production. The production stage involves a set of coordinated operations for the extraction of oil and/or natural gas. Offshore installations for the extraction of oil and natural gas involve a series of physical and chemical processes for processing both oil and natural gas (associated or not) by separating the liquid and gaseous fractions, and their respective specifications. GHG emissions from the oil and gas E&P segment are associated with consumption (principally for generating electricity) and fugitive emissions from venting and flaring. The mapped technologies seek to mitigate emissions from these sources.

The petroleum refining segment includes the separation and conversion of crude oil, by means of physical and chemical processes, into derivatives and final products of greater added value (fuels such as diesel, gasoline and kerosene, among others) and other non-combustible finished products (lubricants, solvents and greases, among others) and chemical industry intermediates (naphtha, ethane and propane, among others). Refining is an energy intensive industry, and GHG emissions in this segment are mostly related to the consumption of fossil fuels. However, emission-reducing technologies for this segment are already mature and often related to energy efficiency measures that do not present barriers to technological development and/or diffusion. A promising technology with significant emission mitigating potential for fluid catalytic cracking (FCC) and hydrogen generation units (HGUs) is carbon capture (discussed below).

With respect to the electricity sector, relevant technologies were identified for unconventional uses of hydroelectricity, offshore wind generation, thermoelectric generation from renewable sources, CO_2 capture in fossil fuel thermoelectric plants and solar energy.

Finally, with respect to the technology needs assessment, we included innovative technologies for the production of advanced biofuels. Advanced biofuels are divided into two classes: advanced light biofuels and medium advanced biofuels. Advanced light biofuels are understood to mean biofuels for the fleet of light vehicles. The main technology for the production of these biofuels is the conversion of lignocellulosic material into ethanol through the hydrolysis process. The ethanol produced using this process is called second generation ethanol. Medium advanced biofuels are intended for heavy vehicles, including vehicles used to transport freight, and biofuels used by the maritime and aviation sectors. Pyrolysis, hydrothermal liquefaction, gasification followed by catalytic synthesis and the oligomerization of alcohols[4] are among the main technologies for converting biomass into these biofuels. The main biofuels produced using these processes are green diesel, biojet and products that can be used as marine biofuels (or biobunkers), among which the aforementioned green diesel, pyrolysis oil and biomethanol stand out. The processing of biogas and biomethane will be addressed in the section on technologies for the waste sector.

[4] The oligomerization of alcohols is a process also known as alcohol-to-jet (ATJ), used for the production of biojet.

Table 10 – Description of technologies that require development and/or diffusion for the energy sector

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
IMPLEMENTATION OF FLARE PILOTS	
Energy (Oil and g as E&P)	This technology on oil and gas platforms eliminates flares with constant emissions, since the device only ignites the flare when natural gas is detected. The technology includes a gas recovery system that consists of a complete closed flare piping system with a safety valve. In addition, a security system is integrated into the system, allowing flares to be ignited in emergency situations.
INSTALLATION OF STEAM RECOVERY UNITS IN STORAGE TANKS	
Energy (Oil and gas E&P)	Vapor recovery systems can be installed to prevent methane and other volatile organic compounds and liquid natural gas from the storage of crude oil from becoming volatilized and vented into the atmosphere. The main technologies used in these systems are adsorption by activated carbon bed, condensation by cooling or compression, absorption by mass transfer columns and separation by membranes.
GAS-TO-LIQUIDS (GTL)	
Energy (Oil and gas E&P)	GTL technology can be used to process the gas on oil and gas platforms to reduce the burning of surplus natural gas, which can be used for the production of synthetic fuels and oil lubricants. It should be noted that this technology is only applicable for oil extracted in the post-salt layer of offshore oil.
CO_2 CAPTURE IN THE PRODUCTION OF OIL AND NATURAL GAS	
Energy (Oil and gas E&P)	The membrane separation method can be used to capture CO_2 directly from the gas extracted from the pre-salt oil fields, specifically on floating production storage and offloading (FPSO) platforms.
CO_2 CAPTURE IN FLUID CATALYTIC CRACKING UNITS	
Energy (Oil refining)	The technology captures CO_2 using oxy-combustion; that is, combustion using oxygen as an oxidizing agent. It can be applied in fluid cracking units, where the main source of emissions is the flue gas from the catalyst regeneration step.
CO_2 CAPTURE IN HYDROGEN GENERATION UNITS	
Energy (Oil refining)	This capture system uses chemical absorption to remove CO_2 from the gas stream using a continuous gas purification system. The chemical absorption process employs a continuous system of gas scrubbers to remove carbon dioxide from the gas stream from steam reforming of natural gas in hydrogen generation units in refineries.
HYDROKINETIC TURBINES	
Energy (Electric)	Hydrokinetic turbines are hydraulic turbines that use the kinetic energy of rivers or tidal currents to generate electricity. By using kinetic energy instead of potential gravitational energy, hydrokinetic turbines can generate electricity from smaller differences in water level. They have potential for application in both urban and rural environments, and can be used to take advantage of the residual kinetic energy in the water flow downstream of conventional hydroelectric plant turbines, providing efficiency gains of up to 5% of the installed potential capacity.

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SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
REVERSIBLE HYDROELECTRIC PLANTS	
Energy (Electric)	Reversible hydroelectric plants provide energy storage by pumping water or hydraulic accumulation. The system consists of pumping water from a lower reservoir to an upper reservoir, usually at off-peak times, in order to store energy, reversing the water flow to generate electricity during peak demand.
REPOWERING HYDROELECTRIC PLANTS	
Energy (Electric)	Repowering hydroelectric power plants consists of efforts to modernize HPPs to generate energy and efficiency gains. Repowering can involve replacing old machinery (such as turbines, generators and rotors), adhering to technological advances for the installation of new machinery in additional reservoirs in existing plants (additional empty reservoirs), and by modernizing facilities and control systems to improve the performance of plants, contributing to energy gains and reserves.
OFFSHORE WIND POWER	
Energy (Electric)	Wind turbine towers can be installed in the ocean in shallow water (up to 30 meters), medium depth (30 to 60 meters) or deep water (more than 60 meters). They share the same technology as onshore wind towers, though they tend to be larger to reduce the cost per MW of installed capacity.
INTEGRATED COMBINED CYCLE WITH BIOMASS GASIFICATION IN THERMOELECTRIC PLANTS	
Energy (Electric)	This electricity generation process uses biomass gasification in a combined cycle of gas and steam turbines. The synthesis gas from the process, properly treated and free of impurities and contaminants, can be used for the generation of products with higher added value, such as the generation of energy in thermoelectric plants.
CONCENTRATED SOLAR POWER (CSP)	
Energy (Electric)	CSP involves the production of electricity by initially converting solar energy into thermal energy and then into electricity in a thermodynamic cycle. CSP can be hybridized so that the plant can partially operate with a backup fuel, which can be of fossil origin (typically natural gas) or renewable, such as biomass.
FLOATING SOLAR POWER PLANTS	
Energy (Electric)	Floating solar systems are an adaptation of conventional photovoltaic energy generation technology for large water surfaces. Floating solar is similar to traditional solar plants, but require a floating structure for panels, an anchoring system, underwater cabling and, in some cases, the installation of inverters on the floating structure.

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SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
CO_2 CAPTURE IN NATURAL GAS THERMOELECTRIC PLANTS	
Energy (Electric)	CO_2 capture can be carried out in combined cycle thermoelectric plants using natural gas. The technology captures carbon dioxide via post-combustion. Typically, post-combustion capture uses chemical absorption processes with amines as a solvent. In these processes, carbon dioxide is absorbed from the gas stream by the solvent and subsequently desorbed, regenerating the solvent and forming a stream of purified CO_2.
CO_2 CAPTURE IN COAL-FIRED THERMOELECTRIC PLANTS	
Energy (Electric)	Post-combustion and pre-combustion CO_2 capture systems can be installed in coal-fired thermoelectric power plants. For conventional combustion boilers, the capture technology indicated is via post-combustion. Pre-combustion capture can be used in thermoelectric plants that use coal gasification systems. CO_2 capture takes place in conventional pulverized coal combustion boilers, using chemical absorption, solids adsorption and membrane separation systems.
SECOND GENERATION ETHANOL	
Energy (Biofuels)	The main technology for converting lignocellulosic materials into ethanol is hydrolysis, which involves hydrolysis and also the saccharification reaction, in addition to a prior stage to break down the lignocellulosic material. The main material used as a raw material for the production of second generation ethanol is bagasse from the production of conventional ethanol. The process is divided into: the pre-treatment stage; hydrolysis stage (which can be acidic or enzymatic); fermentation stage of the released sugars; and the distillation stage to separate vinasse from the ethanol.
GREEN DIESEL	
Energy (Biofuels)	The main technologies for converting biomass into green diesel are pyrolysis, hydrothermal liquefaction, gasification followed by catalytic synthesis and oligomerization of alcohols. Green diesel has many applications, especially in road transport for freight, and offers important environmental advantages compared to mineral diesel.
BIOJET (AVIATION BIOFUEL)	
Energy (Biofuels)	In addition to the technologies for the production of green diesel, alcohol-to-jet (ATJ) technology is another important technology. With ATJ, aviation biofuel is obtained from an intermediate alcohol, such as methanol, ethanol or butanol, among others. The main alcohol used as a raw material in this process is ethanol. The process involves four stages: dehydration, oligomerization, distillation and hydrogenation. It offers significant environmental advantages, considering the carbon intensity of aviation kerosene.
BIOBUNKER FOR MARITIME TRANSPORT	
Energy (Biofuels)	The main technologies for converting biomass into biobunker fuel for maritime transport are pyrolysis, hydrothermal liquefaction, gasification followed by catalytic synthesis and oligomerization of alcohols. Like the other biofuel applications, it has significant potential to mitigate emissions, given the carbon intensity of marine bunker fuel.

Source: the author.

3.3. Selected technologies for the transport sector

We classified the technologies applicable in the transport sector by type: new modes of passenger transport; new modes of freight transport; efficiency of road vehicles; efficiency of trains, vessels and aircraft; and electrification of vehicles.

In the case of new modes for freight transportation, reductions in GHG emissions can be obtained through the adoption of intelligent convoy systems and natural gas for water transport.

With regard to electric vehicles (EVs), they have emerged as one of the most promising technologies for various policies in the transport sector, such as increasing energy security, improving air quality in cities, reducing noise and, in conjunction with a renewable electricity matrix, reducing in GHG emissions. The technology can also be synergistic with other transport strategies, such as electrification of public transport and vehicle sharing (evaluated in new modes of passenger transport), promoting the improvement and efficiency of urban mobility at lower costs.

The consistent growth in EV sales and growing competition to develop new technologies in the sector contribute to the continuous reduction in production costs of batteries, which account for the higher cost of EVs, which may make them more competitive, compared to internal combustion engine (ICE) vehicles. Thus, the expectation is that EVs will continue gaining market share, likely leading the evolution of transport modes and the transformation of the sector (IEA, 2018).

There are two basic types of electric vehicles: hybrids (called plug-in hybrid electric vehicles – PHEV), which have an internal combustion engine in addition to the electric motor and rechargeable battery; and all-electric vehicles, which include battery-powered electric vehicles – BPEV (electric motor powered by a rechargeable battery) and fuel cell electric vehicles – FCEV, where the electric motor is powered by electricity produced in the battery (fuel cell) through chemical reactions with the injected fuel.

Table 11 – Description of technologies that require development and/or diffusion in the transport sector

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
VEHICLE SHARING	
Transport (Road)	Vehicle sharing includes car sharing or paid private vehicle sharing for transportation. In addition, it considers autonomous driving technology as a contribution to vehicle sharing, eliminating the need for the driver or owner of the car.
NATURAL GAS FOR WATER TRANSPORTATION	
Transport (Waterways)	Water transport of freight and passengers is significant in the country. The 30 main Brazilian water routes are between 300 km and 2,000 km in length, transporting more than 160 million metric tons of cargo in 2018 on 378 vessels authorized for water transport (ANTAQ, 2019). Thus, using the pre-salt offshore natural gas supply to fuel vessels has significant potential to reduce the use of fuel oil and diesel, reduce emissions, eliminate the need for fuel supply onshore and, as a co-benefit, provide an efficient way to utilize natural gas.

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SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
USE OF NEW, LIGHTER MATERIALS IN VEHICLES	
Transport (Road)	The technology involves the production of light-weight road transport vehicles, replacing heavy steel components with new and lighter materials, such as high-strength steel, aluminum and polymeric composites reinforced with glass fiber, or advanced materials like magnesium and carbon fiber reinforced composites.
ELECTRIC TURBO-COMPOUND ENGINES	
Transport (Road)	Turbo-compound engines use the energy of exhaust gases from the combustion system. The entire turbocharger and engine system is maintained, but an additional turbine is inserted into the exhaust system, triggering an electric generator that directs energy to the crankshaft.
SMART CONVOY SYSTEM	
Transport (Road)	At the limit of state-of-the-art intelligent systems is smart convoy control. In this system, vehicles (usually trucks) traveling the same route can join together to form a convoy. Only the first vehicle is driven while the others, which are autonomous vehicles, follow it and maintain a safe distance between the vehicles. As autonomous vehicles have much smoother acceleration and deceleration regimes, they are more efficient than the first vehicle in the convoy.
FLEX HYBRID VEHICLES	
Transport (Road)	Hybrid vehicles use a combustion engine and an electric motor. In the case of flex hybrids, the combustion engine can be fueled with ethanol, which is potentially less polluting. In operation, the two engines are used together when at low rotation/speed, and at high rotation/speed, only the combustion engine is used, generating electricity that charges the battery for the electric motor. Hybrid vehicles have greater autonomy than traditional electric motor vehicles.
PARTIAL OR TOTAL ELECTRIFICATION OF TRAINS	
Transport (Rail)	The technology consists of hybrid and electric trains for passenger and freight transport. The benchmark is Rolls-Royce's MTU Hybrid PowerPack hybrid train, which operates with an electric motor and generator, but also has regenerative braking technology to recover energy during braking to store in batteries.
MAGNETIC LEVITATION (MAGLEV) SYSTEMS FOR TRAINS	
Transport (Rail)	Magnetic levitation (Maglev) systems for rail transport allow trains to levitate on rails, reducing drag forces and energy demand. For high-speed rail transport, technologies include magnetic levitation techniques based on electrodynamic levitation or electromagnetic levitation (EML). For urban transport, superconducting magnetic levitation technology is been studied.
PARTIAL OR TOTAL ELECTRIFICATION OF VESSELS USING RENEWABLE ENERGY	
Transport (Waterways)	The technology includes hybrid and electric vessels, both for passenger and cargo transportation. Vessels can be powered by batteries charged from the land power grid, or they can use renewable sources, such as wind and solar, to power propulsion systems.

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SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
IMPROVEMENT OF AIRCRAFT AERODYNAMICS	
Transport (Air)	The technologies to improve aircraft aerodynamics are basically related to the reduction of drag and weight, which can be achieved through design changes, such as Blended Wing Body (BWB) aircraft, or the use of lighter materials.
ELECTRIFICATION OF AIRCRAFT USING RENEWABLE ENERGY	
Transport (Air)	This solar aircraft technology involves equipping planes with photovoltaic cells and rechargeable batteries. In addition, the planes have an engine, crew cabin and energy management system that allows for long flights. The cells are located on the wings of the plane and are used to capture solar radiation and convert it into electrical energy for the propulsion system and electronic control system. The advantage of this type of technology is that it almost eliminates the need for fuel, since the total energy generated is consumed or stored for later use (at night) in secondary batteries.
PLUG-IN HYBRID ELECTRIC VEHICLES	
Transport (Cross-sectoral)	A PHEV combines the benefits of an internal combustion engine and electric motor. The batteries are charged from the grid and supply the electric motor. Once discharged, the internal combustion engine is activated, allowing it to operate like a conventional vehicle.
LIGHT BATTERY POWERED ELECTRIC VEHICLES	
Transport (Cross-sectoral)	Light battery powered electric vehicles use an electric motor powered by batteries, eliminating the internal combustion engine and fuel tank of traditional vehicles. The batteries are recharged with electricity from the grid at charging stations when the vehicle is not in use. They also use regenerative braking technology to generate energy when braking or decelerating.
BATTERY POWERED ELECTRIC BUSES	
Transport (Cross-sectoral)	Battery powered electric buses operate exclusively with a battery powered electric motor, eliminating the internal combustion engine and fuel tank of traditional buses. The main difference between light battery powered electric vehicles and heavy battery powered vehicles, like buses, is the need for a larger battery bank and operational specificities, which require different charging strategies.
HYDROGEN FUEL CELL ELECTRIC VEHICLES	
Transport (Cross-sectoral)	Hydrogen fuel cell electric vehicles have fuel cells that use the chemical energy of hydrogen to produce electricity in an oxidation reaction. Hydrogen production can come from reforming natural gas, as a by-product of the refining process, or via electrolysis, which uses electricity.
ETHANOL FUEL CELL ELECTRIC VEHICLES	
Transport (Cross-sectoral)	These vehicles have electric motors, but instead of being supplied directly by electricity, it is made using a fuel cell that generates energy from ethanol directly.

Source: the author.

3.4. Selected technologies for the waste sector

The waste sector comprises the activities of treatment and disposal of urban solid waste (municipal solid waste – MSW) and industrial waste, as well as urban and industrial effluents. MSW is mainly composed of solid and semi-solid waste from industrial, domestic, hospital, commercial, agricultural and urban cleaning services (FARIA, 2017). Effluents, on the other hand, can be generated in various activities and include waste from homes and industrial and commercial establishments.

Solid waste landfills can be considered biological reactors that principally receive waste and water and produce biogas and leachate. Initially, organic matter is decomposed in an aerobic process and, after reducing the O_2 present in the waste, anaerobic decomposition occurs. The biogas produced is composed mainly of methane (CH_4) and carbon dioxide (CO_2) and traces of ammonia (NH_3), hydrogen (H_2), hydrogen sulphide (H_2S), nitrogen (N_2) and oxygen (O_2).

GHG emissions from the disposal and treatment of liquid effluents depend directly on their composition and source. These effluents can be treated *in situ* (not collected), collected and sent to sewage or waste water treatment plants (WWTPs), or disposed of in bodies of water (IPCC, 2006). When the organic matter in the effluents is degraded under anaerobic conditions, as occurs in WWTPs, CH_4 emissions occur through the production of biogas. The degradation of other effluent components (such as urea, nitrates and proteins) is responsible for N_2O emissions.

The following are technologies that have barriers to development and/or diffusion for large-scale implementation to mitigate emissions in the waste sector.

Table 12 – Description of technologies that require development and/or diffusion in the waste sector

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
GENERATION OF ELECTRICITY FROM BIOGAS WITH MICROTURBINES	
Waste (Effluents, MSW and Agricultural)	Gas microturbines is a promising technology for the generation of electricity from biogas. These small combustion turbines operate at high rotation speeds and in the range of 20 to 250 kW. With microturbines, the air is sucked in at high speed and pressure and then mixed with fuel and burned in the combustion chamber. The gases produced at high temperatures are expanded in the turbine, which drives a generator. The heat from the exhaust gases can be used in the process to heat the air prior to combustion.
BIODIGESTION OF MSW FOR GENERATING ELECTRICITY AND BIOMETHANE	
Waste (MSW)	Biodigestion is the process of decomposition of organic matter in urban solid waste under anaerobic conditions. This process produces biogas and biofertilizers, a liquid residue rich in minerals. Biogas from biodigesters can be used to generate electricity and biomethane.
WASTE INCINERATION	
Waste (MSW and agricultural)	Incineration is a combustion thermochemical cycle that uses MSW as an energy source, reducing its volume and releasing energy in the form of heat. Incinerated waste is decomposed in three phases in an oxidation process: the inert solid phase (ash or slag), the gas phase and the liquid phase (minimal quantities). The gases produced must be treated prior to release into the atmosphere, as they contain GHGs, air pollutants and toxic gases. The ashes can be made inert and disposed of in landfills. Liquids must be neutralized and sent to specific wastewater treatment plants.
PLASMA GASIFICATION OF MSW	
Waste (MSW)	An alternative heat treatment for MSW is the formation of plasma (ionized gas) which produces vitrified solids and synthesis gas. Both products have uses. Vitrified solids can be processed to obtain metals or used in the construction industry, while synthesis gas can be used to produce energy, fuel, chemicals or to extract pure hydrogen, and is considered a promising alternative to fossil fuels.
USE OF AGRICULTURAL AND AGRO-INDUSTRIAL WASTE	
Waste (Agricultural)	Agricultural and agro-industrial waste can be used in the biodigestion process where the organic matter in the waste is decomposed in anaerobic conditions, producing biogas that can be used as biofuel and to generate electricity and mineral-rich biofertilizer. Using waste for co-digestion is a promising technology that uses the high energy potential of agricultural waste for the production of biogas, providing flexibility by using different types of agricultural waste.

Source: the author.

3.5. Selected technologies for the buildings sector

The buildings sector can be divided into residential, commercial and services sub-sectors. In the residential and commercial segments, the use of energy is directly associated with people's quality of life. The services segment is responsible for generating income and jobs in the country.

We mapped innovative technology solutions to mitigate GHG emissions in the segments from energy consumption of equipment and from the building envelope. The technologies include: i) photovoltaic solar induction stoves; ii) distributed generation with renewable micro-generators; iii) smart grid; and iv) Zero Energy Buildings (ZEB).[5]

Table 13 – Description of technologies that require development and/or diffusion in the buildings sector

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
PHOTOVOLTAIC SOLAR INDUCTION STOVES	
Buildings (Residential)	Solar induction stoves use a system that integrates photovoltaic solar panels, batteries and induction plates that, in contact with the pan, generate heat for cooking. With energy storage in batteries, this technology provides greater autonomy and flexibility compared to other solar cookers, allowing the stove to be used in periods without solar energy.
RENEWABLE MICROGENERATION PLANTS: WIND MICROTURBINES, OPV AND THIN FILM CELLS	
Buildings (Residential, Commercial and Services)	Distributed generation (DG) is defined as any power generation plant, of any capacity, with installations connected directly to the distribution system or to consumer units, which can operate in parallel, in isolation or distributed - or not – by the National Electric System Operator. Small DG in buildings is mainly associated with microgeneration solar systems. These systems are commonly installed on roofs, and innovative technologies can associated, such as organic photovoltaic (OPV) cells and thin film photovoltaic cells, in addition to wind microturbines.
SMART GRIDS	
Buildings (Residential, Commercial and Services)	Smart grids are smart electrical networks, that is, networks that use digital technology for the transmission of energy. This technology allows for the communication, collection and analysis of essential data to improve and control the system as a whole. The technology transforms common energy networks into intelligent networks, resulting in new configurations for electrical networks, which allows for the secure integration of renewable energy sources, smart buildings and generators in the network.
NEW MATERIALS FOR ZERO ENERGY BUILDINGS (ZEB)	
Buildings (Residential, Commercial and Services)	These are modern materials used in ZEBs that contribute to their high energy efficiency, such as: lighting control; control of the external air renewal system; thermal insulation of walls and divisions of conditioned environments; systems for measuring energy consumption and production in the building; management systems for end-use energy consumption; on-site generation of renewable energy (wind and solar); and solar heating for water, among others.

Source: the author.

[5] Although ZEBs do not, in themselves, represent a technology in the strictest sense, the concept is associated with technological innovation, as it depends on the development of new materials, distributed generation and smart grids.

3.6. Selected technologies for the agriculture, forestry and other land use sector

The mapping of technologies with gaps in development and/or diffusion in the agriculture, forestry and other land use (AFOLU) sector considered documents such as the Action Plans of the Science, Technology and Innovation for National Development (PACTI) program and others from the Ministry of Agriculture, Livestock and Supply (Mapa) and the Brazilian Agricultural Research Corporation (EMBRAPA). These were discussed in meetings with the technical team of the TNA_BRAZIL project. The technologies were classified into three sub-sectors (agriculture, livestock and other land uses) in order to group together compatible proposals with similar scopes and goals. Finally, we considered cross-sectoral technologies that apply to all AFOLU sub-sectors.

Table 14 – Description of technologies that require development and/or diffusion in the agriculture, forestry and other land use sector

SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
PRECISION AGRICULTURE	
AFOLU (Agriculture)	Precision agriculture (PA) comprises a group of technologies that improve economic returns and reduce environmental impacts; that is, technologies that make agriculture more precise and efficient. These technologies include: i) remote sensing (aircraft and satellite images); ii) proximal sensing of plants, soil, distance and product quality; iii) specific software that stores and processes data for decision making on land preparation, planting, irrigation and efficient application of fertilizers and correctives, among others.
CARBON ALTERNATIVES TO NITROGEN, PHOSPHORUS AND POTASSIUM (NPK)	
AFOLU (Agriculture)	These include systems, strategies, processes or solutions for the use of inoculants for biological nitrogen fixation, comprising phosphate solubilizing microorganisms, rock dust and biological fixation for grasses as low carbon alternatives to NPK.
AGRICULTURAL GENETIC IMPROVEMENT WITH ROBOTIC PHENOTYPING	
AFOLU (Agriculture)	These are systems, strategies, processes or solutions for the development of crops that are more productive, resistant and better adapted to climate change and robotic phenotyping technologies for data collection for the classification and analysis of useful plant characteristics that can be applied in agricultural genetic improvement.
GENETIC IMPROVEMENT IN BEEF CATTLE	
AFOLU (Livestock)	Genetic improvement applied to beef production is a technology that allows for the modification of the genetic composition of herds over generations, aimed at producing animals that are more suited to the demands of the production environment and market. The technology involves the use of chips and computer systems for monitoring animals that have characteristics of interest to generate a database to support the genetic evolution of herds. The data can be used for breeding (pairing) and for the commercialization of genetic material.
NUTRITIONAL SUPPLEMENTATION	
AFOLU (Livestock)	These are systems, strategies, processes or solutions for nutritional supplementation for herds aimed at increasing productivity and reducing emissions. Among the available technologies that require greater diffusion, the following can be highlighted: i) provision of individual troughs with concentrated feed for nursing calves (creep-feeding); ii) nutritional supplementation for growing animals in the dry season; and iii) high energy nutritional supplementation in the fattening phase.

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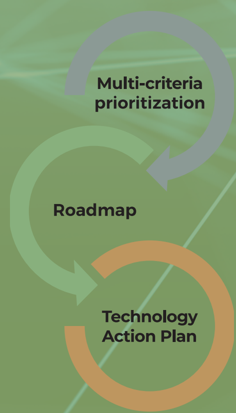
SECTOR (SUB-SECTOR)	DESCRIPTION OF SELECTED TECHNOLOGIES
PRECISION FORESTRY AND SILVICULTURE	
AFOLU (Other land uses)	Precision forestry is based on knowledge of the spatial and temporal variability of production factors and productivity. This knowledge is based on the collection and analysis of geospatial data that is used for localized interventions in the forest and provides the basis for forest management. In addition to using data technologies such as remote sensing, the global positioning system (GPS) and the geographic information system (GIS), the adoption of precision forestry also involves the use of machinery and implements for localized and varied services and application of inputs.
MIXED PLANTING SILVICULTURE WITH EXOTIC AND NATIVE SPECIES	
AFOLU (Other land uses)	These are systems, strategies, processes and solutions for the development of commercial forests that combine exotic and native species with multiple objectives (exploitation of wood products and ecological restoration).
GENETIC IMPROVEMENT OF FORESTS	
AFOLU (Other land uses)	These are systems, strategies, processes or solutions for the development of forest species that are efficient in the use of natural resources and resilient to edaphoclimatic conditions.
SILVICULTURE WITH NATIVE SPECIES FOR RESTORATION	
AFOLU (Other land uses)	These are systems, strategies, processes or solutions for the development of highly productive forest plantations using native species as forest restoration alternatives.
CONSERVATION AND GENETIC IMPROVEMENT OF NATIVE SPECIES	
AFOLU (Other land uses)	Silviculture is the process of producing trees on an industrial and commercial scale. For native species to compete with exotic species, these species need to be genetically modified to improve productivity and quality. This can be achieved with the implementation of genetic improvement and management programs for tree species with economic potential to obtain seeds with genetic quality to sustainably meet the demands of forestry sector industries.
SATELLITE MONITORING	
AFOLU (Cross-sectoral)	Satellite monitoring systems make it possible to obtain data on a specific area by capturing aerial images. These images can identify if an area has native or exotic vegetation cover, level of degradation, land use (agricultural or other activities) and identify the specific characteristics of the landscape. Satellite monitoring can be applied to the main characteristics of the landscape and rural activities, especially for monitoring deforestation, forest restoration and precision agriculture.
VALIDATION SYSTEMS FOR THE RURAL ENVIRONMENTAL REGISTRY	
AFOLU (Cross-sectoral)	These are systems, strategies, processes or solutions aimed at validating data on rural properties and their attributes in the National Rural Environmental Registry System – SICAR (*Sistema Nacional de Cadastro Ambiental Rural*).
CERTIFICATION SYSTEMS FOR CHAINS THAT ARE DEFORESTATION-FREE	
AFOLU (Cross-sectoral)	The basis of a certification system is the systems for monitoring resources/raw materials along the entire production chain. These systems are supported by principles of credibility that are determined by recognized national or international institutions to ensure compliance with the defined requirements. In this case, it consists of systems that certify that products from the agricultural production chain have no impact on direct or indirect deforestation.

Source: the author.

4.

Scoring, Ranking and Prioritization **of Emission Mitigating Technologies**



4. SCORING, RANKING AND PRIORITIZATION OF EMISSION MITIGATING TECHNOLOGIES

From the replies on the multi-criteria forms sent to key stakeholders, the frequency of response distribution, in terms of weights, was initially obtained (figure 7). In this case, we found that most stakeholders gave an equally important weight to the macro-criteria and indicators.

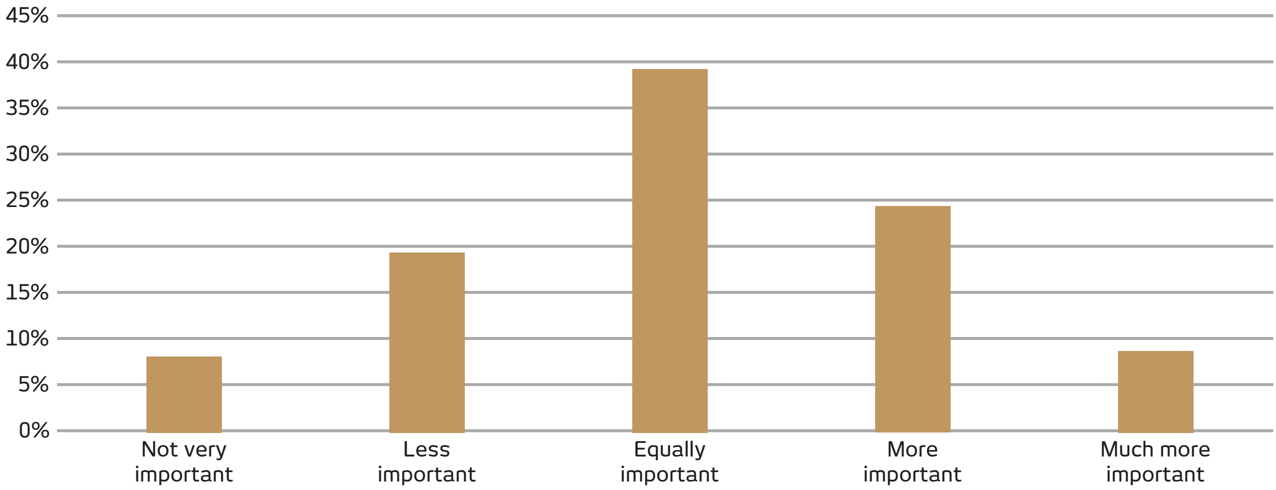
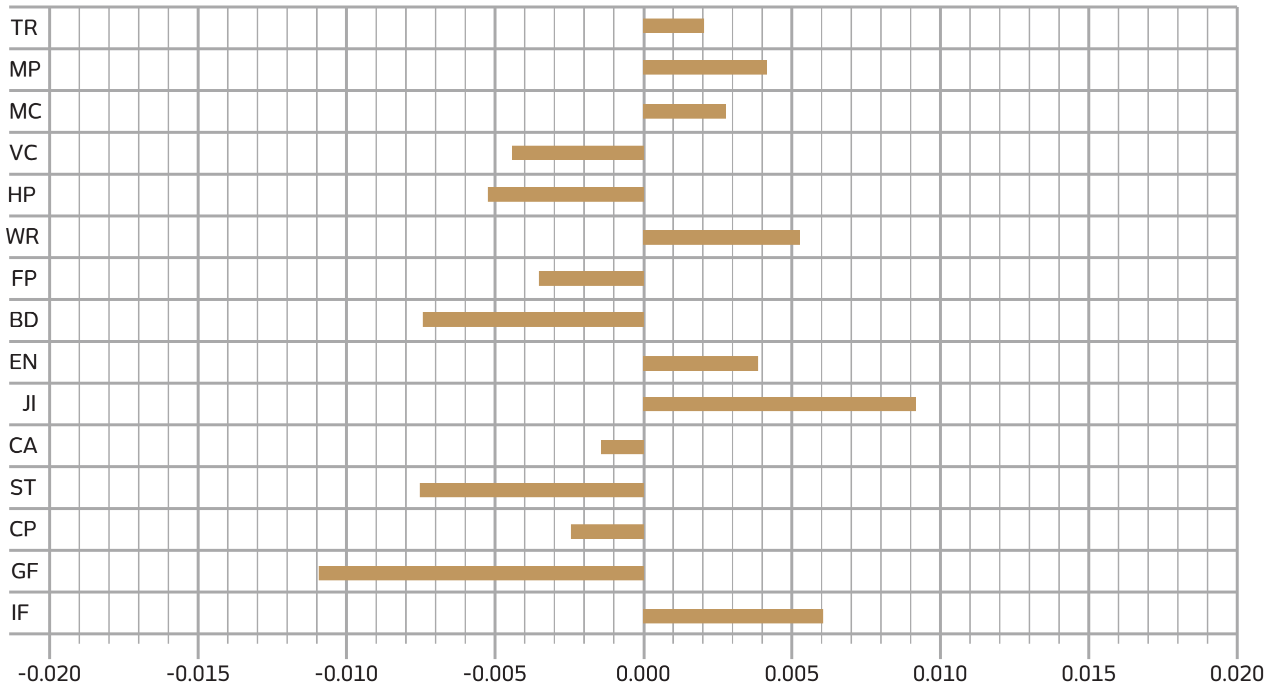


Figure 7 – Distribution of the frequency of responses in relation to the weight of the indicators

Source: the author.

Figures 8 and 9 show the weights obtained with the AHP process for the 15 indicators and four macro-criteria, respectively. Interestingly, despite the main objective of reducing emissions associated with the technologies, the indicator of "job and income generation" was given the greatest weight by key stakeholders. The indicators of "impact on water availability" and "viability of adoption within the current institutional framework" also had high weights attributed to them in the workshops. The other indicators associated with the institutional macro-criterion were considered to be of low importance. For the macro-criteria, the "socio-economic" macro-criterion was considered important and had the greatest weight in the final value, followed by the "technological," "physical" and "institutional" macro-criteria.



Key: TR: Technology Readiness; MP: Mitigation Potential; MC: Mitigation Cost; VC: Vulnerability to Climate Change; HP: Health and pollution reduction; WR: Impact on water availability; FP: Impact on food production; BD: Impact on biodiversity conservation; EN: Impact on energy availability; JI: Jobs and Income generation; CA: Competitive advantages of Brazil; ST: Sinergy with Brazilian national ST&I strategy; CP: Synergy with Brazilian national climate policies; GF: Sinergy with Brazil Country Program for the GCF; IF: Feasibility of adoption under the institutional framework.

Figure 8 – Deviation of the weights assigned to the indicators

Source: the author.

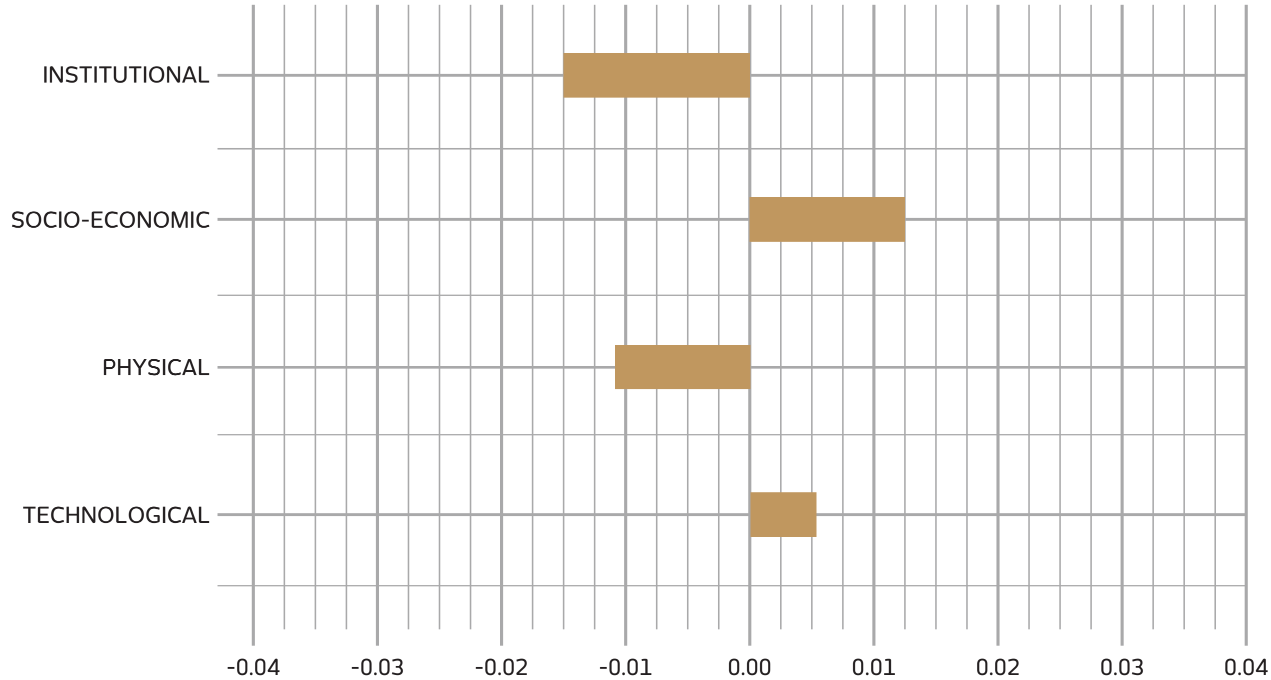


Figure 9 – Deviation of the weights attributed to the macro-criteria

Source: the author.

Following this, the TNA_BRAZIL project technical team scored the selected technologies in each of the 15 indicators according to the criteria determined in the methodology (table 15).

Table 15 – Score of technologies, per indicator

SECTOR (SUBSECTOR)	TECHNOLOGY	INDICATORS														
		TR	MP	MC	VC	HP	WR	FP	BD	EN	JI	CA	ST	CP	GF	IF
Industry (Cement)	Advanced fluidized bed combustion	4	1	5	3	4	3	3	3	3	4	1	3	3	3	3
Industry (Cement)	Geopolymer cement		2	5	3	4	4	3	4	4	3	4	4	3	4	2
Industry (Cement)	Innovative materials for cement	3	3	4	4	4	4	3	4	4	3	2	4	3	4	1
Industry (Cement)	Hybrid solar plants	1	2	1	1	5	3	3	3	4	4	1	3	4	5	1
Industry (Cement)	CO_2 capture	4	5	1	3	3	1	3	3	1	4	1	3	3	2	1
Industry (Cement)	Oxygen enrichment systems	2	5	2	3	3	2	3	3	1	4	1	3	3	2	1
Industry (Cement)	Chemical looping	2	5	1	3	4	2	3	3	1	4	1	3	3	2	1
Industry (Chemical)	Membrane separation	3	1	1	3	3	5	3	3	4	3	3	3	3	3	3
Industry (Chemical)	Catalytic cracking of naphtha	4	1	5	3	4	4	3	3	4	3	3	3	3	3	2
Industry (Chemical)	Use of biomass for olefin production	5	2	2	2	3	2	2	1	2	4	5	4	5	3	4

continues

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SECTOR (SUBSECTOR)	TECHNOLOGY	INDICATORS														
		TR	MP	MC	VC	HP	WR	FP	BD	EN	JI	CA	ST	CP	GF	IF
Industry (Chemical)	Use of H_2 obtained from renewable sources for the production of ammonia and methanol	3	1	1	1	5	2	3	3	2	4	2	3	3	2	2
Industry (Chemical)	CO_2 capture in ammonia production	5	1	4	3	3	3	3	3	3	4	2	3	3	2	1
Industry (Iron and Steel)	Steam reforming of coke oven gas	3	3	1	3	4	3	3	3	4	3	1	3	3	3	1
Industry (Iron and Steel)	Recovery of residual heat from electric arc furnaces using the Organic Rankine Cycle	5	1	1	3	3	3	3	3	4	3	1	3	3	3	2
Industry (Iron and Steel)	Application of SIDERWIN process	2	5	1	3	4	2	3	3	4	3	1	3	3	2	1
Industry (Iron and Steel)	Application of Drying, Pyrolysis and Cooling (DPC) technology in charcoal production	4	5	5	1	4	2	2	1	3	4	5	4	4	4	4
Industry (Iron and Steel)	Application of Ondatec technology in charcoal production	3	5	5	1	4	2	2	1	3	4	5	4	4	4	4
Industry (Iron and Steel)	Blast furnace gas collection and reforming using the IGAR process	1	2	1	3	4	3	3	3	4	3	1	3	3	3	1
Industry (Iron and Steel)	Application of the HIsarna process for fusion reduction	3	5	5	3	4	3	3	3	4	3	1	3	3	3	1
Industry (Cross-sectoral)	Industry 4.0	3	5	5	3	4	4	3	3	4	4	2	5	3	3	2
Industry (Cross-sectoral)	Use of renewable sources in industrial processes	4	5	3	1	4	3	2	2	4	4	4	4	4	4	3
Industry (Cross-sectoral)	Transport of CO_2	5	5	2	3	3	3	3	3	2	4	2	3	3	2	1
Industry (Cross-sectoral)	Storage of CO_2	5	5	3	3	3	3	3	3	3	4	5	3	3	2	1
Energy (Oil and gas E&P)	Implementation of flare pilots	5	1	2	3	4	3	3	3	4	3	3	4	3	2	5
Energy (Oil and gas E&P)	Installation of steam recovery units in storage tanks	5	1	4	3	4	3	3	3	4	3	3	4	3	2	4
Energy (Oil and gas E&P)	Gas-to-liquids (GTL)	3	1	1	3	4	3	3	3	5	4	4	4	3	2	1
Energy (Oil and gas E&P)	CO_2 capture in the production of oil and natural gas	1	2	3	3	3	2	3	3	1	4	4	3	3	2	1

continues

continuation

SECTOR (SUBSECTOR)	TECHNOLOGY	INDICATORS														
		TR	MP	MC	VC	HP	WR	FP	BD	EN	JI	CA	ST	CP	GF	IF
Energy (Oil Refining)	CO_2 capture in fluid catalytic cracking units	2	2	2	3	3	1	3	3	1	4	4	3	3	2	1
Energy (Oil Refining)	CO_2 capture in hydrogen generation units	5	1	2	3	3	1	3	3	1	4	4	3	3	2	1
Energy (Electric)	Hydrokinetic turbines	3	1	4	2	4	3	3	3	5	4	5	3	4	3	3
Energy (Electric)	Reversible hydroelectric plants	5	1	4	2	4	3	3	3	5	3	5	3	4	4	2
Energy (Electric)	Repowering hydroelectric plants	5	1	4	3	3	3	3	3	4	3	5	3	4	3	2
Energy (Electric)	Offshore wind power	1	1	1	2	4	3	3	2	5	4	5	4	4	5	3
Energy (Electric)	Integrated combined cycle with biomass gasification in thermoelectric plants	3	1	2	2	4	1	1	1	4	4	5	4	4	4	3
Energy (Electric)	Concentrated solar power (CSP)	4	2	1	2	4	1	1	1	4	4	5	4	4	5	3
Energy (Electric)	Floating solar power plants	5	1	2	2	4	4	3	2	5	4	5	5	5	5	5
Energy (Electric)	CO_2 capture in natural gas thermoelectric plants	4	1	2	3	3	1	3	3	1	4	4	3	3	2	1
Energy (Electric)	CO_2 capture in coal-fired thermoelectric plants	4	1	2	3	3	1	3	3	1	4	3	4	3	2	1
Energy (Biofuels)	Second generation ethanol	3	1	2	2	3	1	3	3	4	5	5	5	5	5	5
Energy (Biofuels)	Green diesel	3	5	2	2	4	1	1	1	4	5	5	4	5	5	4
Energy (Biofuels)	Biojet (aviation biofuel)	2	3	2	2	4	1	1	1	4	5	5	5	5	5	4
Energy (Biofuels)	Biobunker for maritime transport	3	1	2	2	4	1	1	1	4	5	5	4	5	5	2
Transport (Road)	Vehicle sharing	3	5	1	3	5	3	3	3	3	3	4	5	4	5	1
Transport (Waterways)	Natural gas for water transportation	5	1	4	2	4	3	3	3	2	4	4	3	4	5	2
Transport (Road)	Use of new, lighter materials in vehicles	3	1	5	3	4	3	3	3	4	3	3	3	4	3	3
Transport (Road)	Electric turbo-compound engines	4	1	5	3	4	3	3	3	4	3	3	3	4	3	3
Transport (Road)	Smart convoy system	3	2	5	3	4	3	3	3	4	2	4	3	4	3	1
Transport (Road)	Flex hybrid vehicles	5	5	2	3	5	4	3	3	4	4	5	4	5	5	5
Transport (Rail)	Partial or total electrification of trains	5	1	1	3	5	3	3	3	4	5	3	3	4	5	2
Transport (Rail)	Magnetic levitation (Maglev) systems for trains	2	1	1	3	5	3	3	3	3	4	4	3	4	5	2

continues

continuation

SECTOR (SUBSECTOR)	TECHNOLOGY	INDICATORS														
		TR	MP	MC	VC	HP	WR	FP	BD	EN	JI	CA	ST	CP	GF	IF
Transport (Waterways)	Partial or total electrification of vessels using renewable energy	5	1	4	2	4	3	3	4	4	3	4	3	4	5	3
Transport (Air)	Improvement of aircraft aerodynamics	1	1	1	3	4	3	3	3	3	3	4	3	4	3	2
Transport (Air)	Electrification of aircraft using renewable energy	3	1	1	2	4	3	3	3	4	3	4	3	4	4	2
Transport (Cross-sectoral)	Plug-in hybrid electric vehicles	5	5	1	3	5	4	3	3	4	5	3	3	5	5	4
Transport (Cross-sectoral)	Light battery powered electric vehicles	5	5	1	3	5	3	3	3	4	4	2	3	4	5	4
Transport (Cross-sectoral)	Battery powered electric buses	5	2	3	3	5	3	3	3	4	4	2	3	4	5	4
Transport (Cross-sectoral)	Hydrogen fuel cell electric vehicles	4	3	1	3	5	2	3	3	4	4	2	3	4	5	1
Transport (Cross-sectoral)	Ethanol fuel cell electric vehicles	3	5	1	3	5	4	3	3	4	4	5	4	5	5	5
Waste (Effluents, MSW and Agricultural)	Generation of electricity from biogas with microturbines	4	1	4	3	4	3	3	3	4	4	2	4	5	5	4
Waste (MSW)	Biodigestion of MSW for generating electricity and biomethane	5	1	4	3	4	3	3	3	4	4	2	4	5	5	4
Waste (MSW and agricultural)	Waste Incineration	5	1	3	3	2	3	3	3	4	4	3	4	5	4	4
Waste (MSW)	Plasma gasification of MSW	4	1	1	3	5	3	3	3	4	4	3	4	4	4	4
Waste (Agricultural)	Use of agricultural and agro-industrial waste	5	4	3	4	3	5	5	4	4	4	5	4	5	5	3
Buildings (Residential)	Photovoltaic solar induction stoves	5	1	5	2	5	3	3	3	5	4	5	4	4	4	3
Buildings (Residential, Commercial and Services)	Renewable microgeneration plants: wind microturbines, OPV and thin film cells	4	1	1	1	4	3	3	3	4	4	4	5	5	5	5
Buildings (Residential, Commercial and Services)	Smart grids	3	1	1	3	3	3	3	3	5	5	3	5	4	4	4
Buildings (Residential, Commercial and Services)	New materials for Zero Energy Buildings (ZEB)	3	1	3	3	3	3	3	3	4	5	3	4	4	5	4
AFOLU (Agriculture)	Precision agriculture	4	4	3	4	4	4	4	2	4	2	5	5	4	4	4

continues

continuation

SECTOR (SUBSECTOR)	TECHNOLOGY	INDICATORS														
		TR	MP	MC	VC	HP	WR	FP	BD	EN	JI	CA	ST	CP	GF	IF
AFOLU (Agriculture)	Carbon alternatives to Nitrogen, Phosphorus and Potassium (NPK)	2	4	3	3	4	3	4	4	3	3	5	4	4	4	4
AFOLU (Agriculture)	Agricultural genetic improvement with robotic phenotyping	4	4	3	4	3	4	4	2	4	3	5	4	4	4	4
AFOLU (Livestock)	Genetic improvement in beef cattle	2	4	3	4	4	3	4	2	3	3	5	4	4	4	4
AFOLU (Livestock)	Nutritional supplementation	4	4	3	2	4	3	4	3	3	3	5	4	4	2	4
AFOLU (Other land uses)	Precision forestry and silviculture	2	5	5	4	4	4	3	1	4	2	5	5	5	4	5
AFOLU (Other land uses)	Mixed planting silviculture with exotic and native species	1	5	4	4	4	4	4	4	3	4	5	5	5	5	5
AFOLU (Other land uses)	Genetic improvement of forests	4	4	5	2	4	4	4	2	3	3	5	5	4	5	5
AFOLU (Other land uses)	Silviculture with native species for restoration	1	5	5	5	5	5	4	5	3	5	5	5	5	5	4
AFOLU (Other land uses)	Conservation and genetic improvement of native species	1	4	4	5	4	4	4	5	3	3	5	5	4	5	4
AFOLU (Cross-sectoral)	Satellite monitoring	3	5	4	3	4	5	4	5	4	2	4	5	5	5	5
AFOLU (Cross-sectoral)	Validation systems for the Rural Environmental Registry	2	4	4	3	4	4	4	4	4	3	4	5	5	5	4
AFOLU (Cross-sectoral)	Certification systems for chains that are deforestation-free	2	5	4	3	4	4	4	4	3	4	4	5	5	5	2

Notes:

- [1] Very poor performance
- [2] Poor performance
- [3] Average/neutral performance
- [4] Good performance
- [5] Very good performance

TR: Technology Readiness
MP: Mitigation Potential
MC: Mitigation Cost
VC: Vulnerability to Climate Change
HP: Health and pollution reduction
WR: Impact on water availability
FP: Impact on food production
BD: Impact on biodiversity conservation
EN: Impact on energy availability
JI: Jobs and Income generation
CA: Competitive advantages of Brazil
ST: Synergy with Brazilian national ST&I strategy
CP: Synergy with Brazilian national climate policies
GF: Synergy with Brazil Country Program for the GCF
IF: Feasibility of adoption under the institutional framework

Source: the author.

Based on equation 3, the technologies in table 16 were ranked. The best classified technologies are associated with the AFOLU sector, given the numerous co-benefits associated with their adoption. On the other hand, the technologies for the industrial sector generally appear in the last positions of the ranking, mostly due to the low level of technological maturity.

Table 16 – Ranking of technological needs

TECHNOLOGY	FINAL VALUE	TECHNOLOGY	FINAL VALUE
Silviculture with native species for restoration	4.40	Electrification of aircraft using renewable energy	3.27
Use of agricultural and agro-industrial waste	4.15	Geopolymer cement	3.26
Satellite monitoring	4.14	Storage of CO_2 (industry)	3.25
Flex hybrid vehicles	4.10	Installation of steam recovery units in storage tanks	3.24
Mixed planting silviculture with exotic and native species	4.08	Electric turbo-compound engines	3.23
Conservation and genetic improvement of native species	3.91	Repowering hydroelectric plants	3.23
Genetic improvement of forests	3.90	Biojet (aviation biofuel)	3.21
Ethanol fuel cell electric vehicles	3.89	Natural gas for water transportation	3.18
Validation systems for the Rural Environmental Registry	3.87	Implementation of flare pilots	3.17
Plug-in hybrid electric vehicles	3.85	Catalytic cracking of naphtha	3.17
Precision forestry and silviculture	3.84	Use of new, lighter materials in vehicles	3.11
Certification systems for chains that are deforestation-free	3.80	Application of the HIsarna process for fusion reduction	3.08
Floating solar power plants	3.76	Smart convoy system	3.08
Precision agriculture	3.75	Offshore wind power	3.07
Agricultural genetic improvement with robotic phenotyping	3.71	Hydrogen fuel cell electric vehicles	3.05
Photovoltaic solar induction stoves	3.70	Use of biomass for olefin production	3.05
Light battery powered electric vehicles	3.57	Advanced fluidized bed combustion	2.99
Biodigestion of MSW for generating electricity and biomethane	3.55	Magnetic levitation (Maglev) systems for trains	2.96
Carbon alternatives to Nitrogen, Phosphorus and Potassium (NPK)	3.54	Concentrated solar power (CSP)	2.95
Industry 4.0	3.52	Biobunker for maritime transport	2.92
Battery powered electric buses	3.49	Transport of CO_2 (industry)	2.91
Genetic improvement in beef cattle	3.49	Membrane separation	2.90
Generation of electricity from biogas with microturbines	3.49	Gas-to-liquids (GTL)	2.88
Innovative materials for cement	3.48	Electrification of aircraft	2.85
Application of Drying, Pyrolysis and Cooling (DPC) technology in charcoal production	3.47	CO_2 capture in ammonia production	2.83
Nutritional supplementation	3.45	Integrated combined cycle with biomass gasification in thermoelectric plants	2.70

continues

continuation

TECHNOLOGY	FINAL VALUE	TECHNOLOGY	FINAL VALUE
Renewable microgeneration plants: wind microturbines, OPV and thin film cells	3.42	Recovery of residual heat from electric arc furnaces using the Organic Rankine Cycle	2.69
Second generation ethanol	3.41	Steam reforming of coke oven gas	2.67
Partial or total electrification of vessels using renewable energy	3.41	Improvement of aircraft aerodynamics	2.67
Application of Ondatec technology in charcoal production	3.40	Hybrid solar plants	2.64
Use of renewable sources in industrial processes	3.39	Application of SIDERWIN process	2.56
Green diesel	3.38	CO_2 capture in hydrogen generation units	2.51
Waste Incineration	3.37	Oxygen enrichment systems	2.50
New materials for Zero Energy Buildings (ZEB)	3.36	CO_2 capture (cement)	2.50
Reversible hydroelectric plants	3.36	Chemical looping	2.49
Hydrokinetic turbines	3.31	CO_2 capture in the production of oil and natural gas	2.49
Vehicle sharing	3.31	CO_2 capture in natural gas thermoelectric plants	2.48
Smart grids	3.30	Blast furnace gas collection and reforming using the IGAR process	2.48
Plasma gasification of MSW	3.28	CO_2 capture in coal-fired thermoelectric plants	2.43
Partial or total electrification of trains	3.28	Use of H_2 obtained from renewable sources for the production of ammonia and methanol	2.42

Source: the author.

Given the physical and financial schedule of the TNA_BRAZIL project, the NPD determined that 12 technology packages should be prioritized. In view of this, there was ample debate among the members of the TAC for this selection. Table 17 shows the technologies selected, per sector and sub-sector.

Table 17 – Number of prioritized technologies, per sector and sub-sector and selection methods

SECTOR	SUB-SECTOR	TECHNOLOGY SELECTION METHOD			
		ORS	SES	RSE	SRE
Industry	Cement	-	1	1	1
	Chemical	-	-	-	-
	Iron and Steel	-	-	-	-
	Cross-sectoral	-	1	1	1
Energy	Oil and gas E&P	-	-	-	-
	Oil refining	-	-	-	-
	Electric	-	1	1	1
	Biofuels	-	1	-	-
Transport	-	3	2	2	2
Waste	-	1	2	1	1
Buildings	-	-	2	-	1
AFOLU	Agriculture and Livestock	-	-	-	2
	Other land uses and Cross-sectoral	8	2	6	3

Notes:
ORS – Ordinal selection
SES – Selection by sectoral equity
RSE – Selection by representativeness of sectoral emissions
SRE – Selection by sub-sectorial representation of emissions

Source: the author.

Consensus was reached on the prioritization of technologies using the method of sub-sectoral representativeness of emissions, thus ensuring that the final objective of the technology needs assessment was achieved with equity in the distribution of measures in the key sectors.

In addition, the TAC recommended changing the scope of the technology from "silviculture and native species for restoration" to "silviculture and genetic improvement of native species," thus taking advantage of synergies with the technologies selected for the other AFOLU sub-sectors, which also involve genetic improvement. For forest restoration, it was also decided to consolidate the technology of "mixed planting silviculture (exotic and native)" and "native species silviculture for restoration," thus resulting in the technology of "silviculture with mixed planting for restoration".

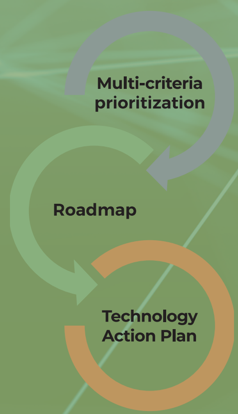
The final list of selected technologies for each respective sector and sub-sector is presented in table 18.

Table 18 – Prioritized technologies per sector and sub-sector

SECTOR	SUB-SECTOR	TECHNOLOGY
Industry	Cement	Innovative materials for cement
	Cross-sectoral	Industry 4.0
Energy	Electric	Floating solar power plants
Transport	Road and Cross-sectoral	Flex hybrid vehicles
		Ethanol fuel cell electric vehicles
Waste	Agricultural	Use of agricultural and agro-industrial waste
Buildings	Residential	Photovoltaic solar induction stoves
AFOLU	Agriculture and Livestock	Precision agriculture
		Genetic improvement of beef cattle
	Other land uses and Cross-sectoral	Silviculture and genetic improvement of native species
		Satellite monitoring
		Silviculture with mixed planting for restoration

Source: the author.

Conclusions



CONCLUSIONS

The Ministry of Science, Technology and Innovations (MCTI), with the support of United Nations Environment Programme (UNEP) and technical partners, identified 82 technologies to promote low carbon and climate resilient development in Brazil.

A participatory process involving diverse key stakeholders was carried out to determine the priority mitigation technologies for different economic sectors in Brazil. The stakeholders were consulted in all methodological stages, allowing for a comprehensive and participatory assessment of technology needs. Thus, the views and interests of these stakeholders was registered to encourage their engagement in the adoption of low carbon technologies.

The indicators that most impacted the selection of technologies are associated with the generation of jobs and income, impact on water availability and the institutional framework. This may be related to, respectively, the current economic crisis in Brazil, aggravated by the effects of the COVID-19 pandemic, which has increased the unemployment rate in recent years; the dependence of the country's electricity generation system and agriculture on water resources; and the country's fragile institutional framework to remove barriers to the development and diffusion of the technologies.

With the scores and weights of the criteria, the technologies were ranked according to their final value. The first positions in the ranking were technologies for the AFOLU sector, with emphasis on the Other Land Uses sub-sector. To avoid concentrating measures in a single sector, rather than select the priority technologies according to best classification, an alternative method was employed that ensures a better balance among the sectors.

Thus, with ample engagement and consensus from the members of the SCs and TAC of the TNA_BRAZIL project, the following priority technologies for the elaboration of the TAPs were defined: i) precision agriculture; ii) use of agricultural and agro-industrial waste; iii) floating solar power plants; iv) photovoltaic solar induction stoves; v) industry 4.0; vi) innovative materials for cement; vii) genetic improvement in beef cattle; viii) satellite monitoring; ix) silviculture with mixed planting for restoration; x) silviculture and genetic improvement of native species; xi) ethanol fuel cell electric vehicles; and xii) flex hybrid vehicles.

The recent release of TNA_BRAZIL project publications and financing tool has the potential to foster the development and diffusion of climate technologies to promote sustainability in the country:

- Technology Action Plans for the energy system, agriculture, forestry and othe land use sectors (MCTI, 2021b; 2021c);
- Financing Guidelines for the Technologies and Technology Action Plans in the TNA_BRAZIL Project (MCTI, 2021d); and
- Electronic guide to financing options for the technologies prioritized in the TNA_BRAZIL project (MCTI, 2021e).

The importance of diffusion and financing options for projects based on the TAPs lies in the potential of these technologies to foster economic growth and sustainable development with the use of low carbon technologies that reduce GHG emissions. These actions become even more important in the current context and the post-pandemic future, as information is essential for the implementation of projects that depend on national or international funding. This is because the project prioritizes technologies that are representative of national circumstances, and funding agencies, such as the GCF, require this prioritization to provide resources.

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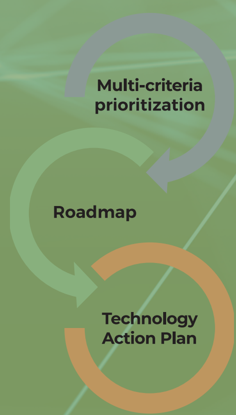
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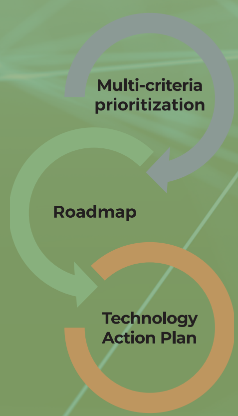
Appendices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APPENDIX I – MEMBERS OF THE TECHNICAL ADVISORY COMMITTEE (TAC) AND SECTORAL CHAMBERS (SC)

NAME	INSTITUTION
TECHNICAL ADVISORY COMMITTEE	
Luís Fernando Badanhan	Ministry of Mines and Energy
Sérgio Ferreira Cortizo	Ministry of Mines and Energy
Mário Henrique Rodrigues Mendes	Ministry of Environment
Délio Noel Gomes de Carvalho	Ministry of Environment
Gustavo Saboia Fontenele e Silva	Ministry of Economy
Fábio Sakatsume	Ministry of Economy
Katia Marzall	Ministry of Agriculture, Livestock and Supply
Eleneide Doff Sotta	Ministry of Agriculture, Livestock and Supply
Raquel Breda dos Santos	GCF Designated National Authority – Ministry of Economy
Ronan Luiz da Silva	GCF Designated National Authority – Ministry of Economy
Fernando Araldi	Ministry of Regional Development
Danielle Costa de Holanda	Ministry of Regional Development
Gustavo Barbosa Mozzer	Brazilian Agricultural Research Corporation
Maria José Amstalden Moraes Sampaio	Brazilian Agricultural Research Corporation
Rodrigo Vellardo Guimarães	Energy Research Company
Mariana Lucas Barroso	Energy Research Company
Fillipe Augusto da Costa Garcia	National Petroleum, Natural Gas and Biofuels Agency
Joana Borges da Rosa	National Petroleum, Natural Gas and Biofuels Agency
Davi Bomtempo	National Confederation of Industry
Marcos Vinícius Cantarino	National Confederation of Industry
Rodrigo Rodrigues de Fonseca	Financier of Studies and Projects
Felipe Arias Fogliano de Souza Cunha	Financier of Studies and Projects
Márcio Rojas da Cruz	Ministry of Science, Technology and Innovations
Sonia Regina Mudrovitsch de Bittencourt	Ministry of Science, Technology and Innovations
Antônio Marcos Mendonça	Ministry of Science, Technology and Innovations
Régis Rathmann	Ministry of Science, Technology and Innovations
Cibele Dutra de França	Ministry of Infrastructure
AFOLU SECTORAL CHAMBER	
Rodrigo Lima	Agroicone
Bernardo Rudorff	Agrosatelite Geotecnologia Aplicada
Julio Cesar Minelli	Association of Biofuel Producers
Nelson Ananias Filho	National Confederation of Agriculture
Eduardo Assad	Brazilian Agricultural Research Corporation
Mariano Cenamo	Amazon Conservation and Sustainable Development Institute
Jean Pierre Ometto	National Institute for Space Research
Claudio Almeida	National Institute for Space Research
Felipe Lenti	Amazon Environmental Research Institute

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Julia Shimbo	MAPBIOMAS
Carlos Nobre	University of São Paulo
Paulo Artaxo	University of São Paulo
Viviane Romeiro	World Resources Institute
INDUSTRY AND ENERGY SECTORAL CHAMBER	
Valéria Lima	Brazilian Aluminum Association
Fernando Zancan	Brazilian Mineral Coal Association
Marina Mattar	Brazilian Chemical Industry Association
Stefan Jacques David	Brazilian Association of Glass Industries
Rodrigo Lopes Sauaia	Brazilian Association of Photovoltaic Solar Energy
Stephanie Betz	Brazilian Association of Photovoltaic Solar Energy
Ivonice Campos	Brazilian Association of Photovoltaic Solar Energy
Maria Fernanda Pelizzon Garcia	Environmental Company of the State of São Paulo
Marcelo Poppe	Management and Strategic Studies Center
Bárbara Bressan	Management and Strategic Studies Center
Rafaele Lebani	Companhia Paulista de Força e Luz
Nivalde de Castro	Federal University of Rio de Janeiro
Roberto Musser	Light
Andrea Galhego	Federation of Industries of the State of Rio de Janeiro
Ana Toni	Instituto Clima e Sociedade
Maurício Henriques Jr.	National Institute of Technology
Denise Alho	Petrobras
Gonzalo Visedo	National Cement Industry Association
Edmilson Moutinho dos Santos	University of São Paulo
Oswaldo Lucon	University of São Paulo
Lucila Caselato	Instituto Aço Brasil
TRANSPORT, WASTE AND BUILDINGS SECTORAL CHAMBER	
José Antonio Sena do Nascimento	Mineral Technology Center
Maria Fernanda Pelizzon Garcia	Environmental Company of the State of São Paulo
Marcelo Poppe	Management and Strategic Studies Center
Bárbara Bressan	Management and Strategic Studies Center
Patrícia Boson	National Transport Confederation
Erica Vieira Marcos	National Transport Confederation
Priscila Bernardes Alvares	National Confederation of Municipalities
Karla França	National Confederation of Municipalities
Bruna Cerqueira	Local Governments for Sustainability
Ana Toni	Instituto Clima e Sociedade
Renata Nascimento Szczerbacki	Petrobras
Márcio D'Agosto	Federal University of Rio de Janeiro
Suzana Kahn Ribeiro	Federal University of Rio de Janeiro
Dominique Mouette	University of São Paulo
Edmilson Moutinho dos Santos	University of São Paulo
Oswaldo Lucon	University of São Paulo

Source: the author.

APPENDIX II – CTC MEMBERS AND CS SPECIALISTS INVOLVED IN THE MULTI-CRITERIA ANALYSIS

NAME	INSTITUTION
Cláudio Almeida	National Institute for Space Research
Júlio Minelli	Association of Biofuel Producers
Fernando Luiz Zancan	Brazilian Mineral Coal Association
Jean Pierre Ometto	National Institute for Space Research
Marco Aurélio Araújo	Ministry of Economy
Maria Fernanda Pelizzon Garcia	Environmental Company of the State of São Paulo
Oswaldo Lucon	University of São Paulo
Roberto Zecchini Cantinho	Ministry of Science, Technology and Innovations
Rodrigo Braga	Ministry of Science, Technology and Innovations
Rodrigo Costa	Agroicone
Stephanie Betz	Brazilian Association of Photovoltaic Solar Energy
Mauricio Francisco Henriques Jr.	National Institute of Technology
Marcelo Poppe	Management and Strategic Studies Center
Mauro Meirelles Oliveira dos Santos	Ministry of Science, Technology and Innovations
Viviane Romeiro	World Resources Institute
Patricia Boson	National Transport Confederation
Erica Vieira Marcos	National Transport Confederation
Marco Aurélio Araújo	Ministry of Economy
Raphael Stein	National Bank for Economic and Social Development
Sérgio Ferreira Cortizo	Ministry of Mines and Energy
Fernando Araldi	Ministry of Regional Development
Joana Borges Rosa	National Petroleum, Natural Gas and Biofuels Agency
Mário Henrique Mendes	Ministry of Environment
Délio Noel Gomes Carvalho	Ministry of Environment
Katia Marzall	Ministry of Agriculture, Livestock and Supply
Sonia Regina Bittencourt	Ministry of Science, Technology and Innovations
Fillipe Augusto da Costa Garcia	National Petroleum, Natural Gas and Biofuels Agency
Antônio Marcos Mendonça	Ministry of Science, Technology and Innovations
Daniela Merlo	CAIXA
Eleneide Sotta	Ministry of Agriculture, Livestock and Supply
Morenno de Macedo	CAIXA
Euler Lage	National Petroleum, Natural Gas and Biofuels Agency
Gustavo Barbosa Mozzer	Brazilian Agricultural Research Corporation
Mariana Lucas Barroso	Energy Research Company
Luis Fernando Badanhan	Ministry of Mines and Energy
Márcio Rojas da Cruz	Ministry of Science, Technology and Innovations
Felipe A. F. de Souza Cunha	Financier of Studies and Projects

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Rodrigo Rodrigues Fonseca	Financier of Studies and Projects
Marcus Vinicius Cantarino	National Confederation of Industry
Davi Bomtempo	National Confederation of Industry
Raquel Breda dos Santos	Ministry of Economy
Ronan Luiz da Silva	Ministry of Economy
Maria José A. M. Sampaio	Brazilian Agricultural Research Corporation
Rodrigo Vellardo Guimarães	Energy Research Company
Danielle Costa Holanda	Ministry of Regional Development
Felipe Lenti	Amazon Environmental Research Institute
Barbara Bressan	Management and Strategic Studies Center
Danielly Godiva Santana Molleta	Ministry of Science, Technology and Innovations
Dominique Mouette	University of São Paulo
Edmilson Moutinho dos Santos	University of São Paulo
Fabio Sakatsume	Ministry of Economy
Giovana Dalpont	Brazilian Mineral Coal Association
Giovanna Lunkmoss de Christo	Ministry of Science, Technology and Innovations
Lidiane Melo	Ministry of Science, Technology and Innovations
Lucila Caselato	Instituto Aço Brasil
Marcela Aboim Raposo	Ministry of Science, Technology and Innovations
Giampaolo Queiroz Pellegrino	Brazilian Agricultural Research Corporation
Régis Rathmann	Ministry of Science, Technology and Innovations

Source: the author.

APPENDIX III – SCORE SHEETS OF SELECTED TECHNOLOGIES IN THE SECTORS OF THE ENERGY SYSTEM, AGRICULTURE, FORESTRY AND OTHER LAND USES

MACRO-CRITERIA	INDICATOR	SCORE
ADVANCED FLUIDIZED BED COMBUSTION (INDUSTRY/CEMENT)		
Technological	Technology Readiness	4
	There are demonstration scale plants in Japan (200 t/day) and China (1,000 t/day). That corresponds to a TRL 8 (1).	
	Mitigation potential	1
	The estimated mitigation potential for the technology in Brazil is 3,143 Gg of CO_2 annually, referring to 20% of the cement industry energy emissions (1).	
	Mitigation cost	5
	This technology can reduce capital and operational costs by 21% and 26%, respectively (2). Therefore, it can be seen as a negative abatement cost option.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	This technology can reduce NO_2 emissions by 30% in comparison to the current industrial practice (1).	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	3
	A thermal energy demand reduction of 300 MJ/t of cement is achieved with the use of this technology, while an increase of 9 kWh/t of cement in electricity consumption is observed (1). Therefore, the technology is considered neutral on this criterion.	
	Jobs and income generation	4
	The cost reduction promoted by this technology in comparison to the conventional process (1) can be seen as an enhancement of the capital productivity. That has a potential to generate income for the society.	
	Competitive advantages of Brazil	1
	The State-of-The-Art of this technology is currently developed in Asian countries (1). No Brazilian research centers studying this technology were identified, nor any mentions to this technology in the Brazilian cement industry plans (3).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although technology transfer is encouraged (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	2
	The needs for importing a technology package is seen as a major barrier by the Brazilian industry (7). Other barriers are related to the need for a substitution of an important plant equipment, which require financial access (the BNDES FINEM credit line (8) could eventually be used) and training for the operators.	

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MACRO-CRITERIA	INDICATOR	SCORE
	GEOPOLYMER CEMENT (INDUSTRY/CEMENT)	
Technological	Technology Readiness	5
	Geopolymeric cements are considered a mature technology, having a TRL rating of 9 (9). There is even a company selling geopolymer cement in Brazil (10).	
	Mitigation potential	5
	The mitigation potential is 25,771 Gg CO_2 per year, qualifying the technology to score 5 of the established range. A 65% reduction in emissions from the cement industry in the reference year was considered, the average value of the range indicated in (11).	
	Mitigation cost	1
	There are different estimates of the abatement cost in the literature for geopolymer cement, ranging from negative values, that is, lower production costs in relation to Portland cement (9,12), at costs in the range of 50 USD/tCO_2 (13). However, in a consultation with a national supplier of geopolymeric cement, a budget of 10 to 15 times higher than the use of Portland cement was obtained for the same service, which represents an abatement cost greater than 3,000 USD/tCO_2 avoided, the premises of this study. Thus, score 1 was conservatively adopted for technology in this indicator.	
	Vulnerability to climate change	4
	Geopolymer cement concretes, in general, have characteristics superior to traditional Portland cement in terms of resistance to high temperatures (14), which is an important constructive element for the resilience of objects, equipment or buildings in the face of the occurrence of extreme climatic events that result in fires. Furthermore, given that the hardening time of geopolymer cement concrete is less than conventional (14), the use of technology can reduce the repair time of a logistics network damaged by extreme events. Thus, the technology was considered to be good for the indicator, obtaining a score of 4.	
Physical	Health and pollution reduction	4
	Geopolymeric cements can be produced from waste from industrial processes, such as ashes from fuel from thermoelectric plants, blast furnace slag (steel industry), the disposal of which generates damage to the environment (14,15). Research also evaluates the use of sludge from mining processes, currently disposed in dams, for the production of geopolymer cement (16,17). Thus, the technology was considered positive for the indicator, obtaining a score of 4.	
	Impact on water availability	4
	The ratio between the water collected and the use of cement for 2016 reported by Votorantin (18) was 0.188 m^3/t. Hosseinian and Nezamoleslami (19), however, highlight that virtual water consumption can be more than ten times higher than the direct consumption of the resource in a Portland cement industry, mainly due to the intense burning of fossil fuels in the clinker production. Therefore, by reducing clinker production and energy demand, the use of alternative materials also helps to reduce water consumption in cement industry.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	4
	According to the WBCSD methodological guide for assessing the impact of the cement industry on biodiversity, actions that result in deforestation, construction of ancillary structures and operating yards have a negative impact on biodiversity, while recovery of mining areas, protection of zones of biodiversity value, ecological restoration, actions focused on species and creation of new habitats after mining activity are positive for biodiversity (20). Thus, the use of waste from mining processes or others that generate environmental liabilities as alternative materials for cement is potentially beneficial to biodiversity.	

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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	Impact energy availability	4
	There is a reduction of about 59% in the consumption of thermal energy for the production of geopolymer cement in relation to the synthesis of Portland cement (11). Thus, technology was considered positive for this indicator, having received a score of 4.	
	Jobs and income generation	3
	No comparative studies were found between the labor intensity of the production of geopolymer cement and Portland cement, and the job chain downstream of the production process is similar for both products. Thus, the neutral technology for this indicator was assumed, with a score of 3.	
	Competitive advantages of Brazil	5
	In terms of production factors, Brazil has an abundance of raw materials for the production of geopolymer cement, especially when considering mining waste. Federal universities in the state of Minas Gerais (UFOP and UFMG) studying the production of geopolymeric cement from iron mining tailings (16,17).	
Institutional	Synergy with the country's National Strategy for ST&I	4
	A tecnologia não é explicitamente mencionada no documento, porém o fomento à pesquisa, desenvolvimento tecnológico e a inovação em materiais, The technology is not explicitly mentioned in the document, but the promotion of research, technological development and innovation in materials, with a focus on adding value, increasing competitiveness and reducing external dependence, is proposed under the "National Strategy for Manufacturing Advanced", which could include this technology (4).	
	Synergies with national climate policies	3
	Substitution of materials is pointed out in the PNMC as a mitigation option for the industrial sector, but in a generic way (21). The other climate policy instruments evaluated do not mention the replacement of materials	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicitly mentioned in the Brazil's Country Program for the Green Climate Fund. However, among the thematic axes and proposed investment areas, there is the "sustainable infrastructure", which could cover this technology.	
	Feasibility of adoption under the institutional framework	2
	Material specifications are lacking, but the results of several studies indicate that geopolymer concrete must perform at least similar to Portland cement concrete in tests for existing specifications (14,16,22,23).	

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MACRO-CRITERIA	INDICATOR	SCORE
	INNOVATIVE MATERIALS FOR CEMENT (INDUSTRY/CEMENT)	
Technological	Technology Readiness	4
	There are several cement-based materials that emit less CO_2 in their production process compared to Portland cement, at different levels of technological readiness. Aether and Solidia cements are classified with TRL 9, while for Celitement cement the TRL varies between 4 and 5 (9). Thus, in order to contemplate products with more advanced maturity stages but maintaining the premise that there are still other materials with technological development needs, the technology is classified as having a score of 4 in this indicator. This is the case for the application of supplementary cementitious materials for the production of cement, and it is necessary to carry out experimental tests of addition of these with a view to a limited proportion of 50% of clinker in volume to the cement.	
	Mitigation potential	3
	An average mitigation potential is estimated at 13,877 Gg of CO_2 per year (11), which is consistent to the score 3 in the adopted metrics.	
	Mitigation cost	4
	Some innovative cements can have production costs very similar to the conventional Portland cement, as the Aether, while others can cost even less, like Solidia (9, 13). Hence, a score of 4 is given to this technology in this indicator.	
	Vulnerability to climate change	3
	Some innovations in materials for cements can have better properties than the conventional Portland cement (9). However, in a conservative basis, the technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	Innovative materials alternative to Portland cement that aim to mitigate emissions, in general, have as strategy to reduce the use of clinker (9), whose production in the calcination furnaces is a source of emissions of atmospheric pollutants, such as particulate matter, SO_2 and NO_x (24–27). Thus, by reducing the clinker content in the cement industry, a reduction in air pollutant emissions is expected. Therefore, technology received a score of 4 on the indicator.	
	Impact on water availability	4
	The ratio between the water collected and the use of cement for 2016 reported by Votorantin (18) was 0.188 m^3/t. Hosseinian and Nezamoleslami (19), however, highlight that virtual water consumption can be more than ten times higher than the direct consumption of the resource in a Portland cement industry, mainly due to the intense burning of fossil fuels in the clinker production. Therefore, by reducing clinker production and energy demand, the use of alternative materials also helps to reduce water consumption in cement industry.	
	Impacto on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	4
	According to the WBCSD methodological guide for assessing the impact of the cement industry on biodiversity, actions that result in deforestation, construction of ancillary structures and operating yards have a negative impact on biodiversity, while recovery of mining areas, protection of zones of biodiversity value, ecological restoration, actions focused on species and creation of new habitats after mining activity are positive for biodiversity (20). Thus, the use of waste from mining processes or others that generate environmental liabilities as alternative materials for cement is potentially beneficial to biodiversity.	

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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	**Impact on energy availability**	4
	The substitution of clinker for other less energy intensive materials reduces the thermal energy demand of the production process (9,11,13).	
	Jobs and income generation	3
	Considering that there are no changes in the chain of use of these materials, the technology was considered neutral in this indicator, receiving a score of 3.	
	Competitive advantages of Brazil	2
	The innovative materials considered are currently being developed in other countries. Despite this, the major cement companies that finance the main products operate in Brazil, such as LafargeHolcim, which is behind the development of Aether cement. In addition, the national cement industry is committed to innovation for better environmental results, given the recent publication of a Roadmap for the Brazilian cement industry (3). Therefore, technology received a score of 2 in this criterion.	
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	The technology is not explicitly mentioned in the document, but the promotion of research, technological development and innovation in materials, with a focus on adding value, increasing competitiveness and reducing external dependence, is proposed under the "National Strategy for Manufacturing Advanced", which could include this technology (4).	
	Synergies with national climate policies	2
	Substitution of materials is pointed out in the PNMC as a mitigation option for the industrial sector, but in a generic way (21). The other climate policy instruments evaluated do not mention the replacement of materials.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicitly mentioned in the Brazil's Country Program for the Green Climate Fund. However, among the thematic axes and proposed investment areas, there is the "sustainable infrastructure", which could cover this technology.	
	Feasibility of adoption under the institutional framework	1
	These innovative materials lack norms and specification for its use in Brazil, since the country's norms for cement are prescriptive for its composition. Also, the need to import materials and components for the production of innovative cements in Brazil are a major barrier.	

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MACRO-CRITERIA	INDICATOR	SCORE
HYBRID SOLAR PLANTS (INDUSTRY/CEMENT)		
Technological	Technology Readiness	1
	This technology has currently a TRL 3 (9), with a perspective to achieve a TRL 4 to 5 with the SOLPART project (28).	
	Mitigation potential	2
	While still early for a precise estimation of the mitigation potential of this technology (29), experts estimate a reduction of 60% to 100% of the energy emissions of the cement industry. Adopting the conservative value of 60%, the mitigation potential of this technology would be 9,430 Gg CO_2 per year.	
	Mitigation cost	1
	Given the low TRL and a lack of knowledge of its actual cost in full scale operational conditions, a conservative score of 1 is given to this technology in this indicator.	
	Vulnerability to climate change	2
	The renewable energy sources availability is more impacted by climate change than fossil fuels, which make this process more vulnerable to climate change than the conventional (31).	
Physical	Health and pollution reduction	4
	The use of solar energy to meet thermal demands can reduce air pollutants emissions associated to the combustion of fossil fuels (24, 25, 27).	
	Impact on water availability	4
	Fossil fuel combustion in responsible for a major part of the water consumption in the cement industry (19). Hence, the use of solar energy instead can impact positively the local water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The substitution of fossil fuels by solar energy in the cement industry (28,30) saves these fuels for being used in other sectors, increasing the energy availability to the society.	
	Jobs and income generation	4
	The introduction of an innovative vector to use an available renewable resource in the cement industry can foster the creation of new value chains. That has a potential to create direct and indirect jobs, as observed in the energy sector (32,33).	
	Competitive advantages of the country	5
	The current State-of-The-Art for this technology is currently developed in other countries (28). Also, the Brazilian cement industry roadmap do not include this technology in its short-term scope (3).	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although the use of solar energy resources is considered strategic in the document (4).	
	Synergies with national climate policies	4
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although solar energy assumes a central role in the NDC and PNMC (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	Concentrated Solar Power is specifically cited in the document as one of the options that should be prioritized for the energy mix diversification (6).	
	Feasibility of adoption under the institutional framework	1
	This technological change requires major changes in existing plants for retrofitting or the construction of new plants. That implies significant barriers regarding technology, financing and training for operation.	

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MACRO-CRITERIA	INDICATOR	SCORE
	CO_2 CAPTURE (INDUSTRY/CEMENT)	
Technological	Technology Readiness	4
	This technology has been demonstrated by Norcem, under the CEMCAP project, and has a TRL 8 (34).	
	Mitigation potential	5
	A mitigation potential of 37,666 Gg CO_2 per year is estimated for this technology, assuming a capture potential of 95% of the total emissions of the cement industry (35).	
	Mitigation cost	1
	The abatement cost for this technology is estimated at 88 USD/tCO_2 (36).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	2
	The CO_2 capture process enhances the water demand of a cement plant for consumption, cooling and steam generation.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	1
	A parasitic energy consumption is observed for absorption-based CCS, especially for solvent regeneration (35,37).	
	Jobs and income generation	4
	A new value chain associated to CCS operations is expected to arise once industrial plants start to invest in this technology. That would induce the creation of new jobs.	
	Competitive advantages of the country	2
	Currently, there are no CCS projects in Brazilian cement plants. However, the Brazilian cement industry roadmap cites this technology as a possible way to reduce the emissions of this sector (3).	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although there is a strategic axis specifically related to climate technologies (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC cites the promotion of new benchmarks of clean technologies and sustainable infrastructure as one of its measures (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF. However, one of the investment areas of the program is "sustainable infrastructure", which could include th CCS value chain (6).	
	Feasibility of adoption under the institutional framework	1
	There are many regulatory gaps in Brazil for CCS operations, especially regarding the stakeholder responsabilities in each phase of the productive structure (38). Besides, the country lacks a CO_2 transport structure for conecting sources to sinks (35). Also, there are no climate change mitigation policies in place to incentivise investment on CCS in Brazil.	

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MACRO-CRITERIA	INDICATOR	SCORE
	OXYGEN ENRICHMENT SYSTEMS (INDUSTRY/CEMENT)	
Technological	**Technology Readiness**	2
	The technology has currently a TRL 4 to 5 (34).	
	Mitigation potential	5
	A mitigation potential of 37,666 Gg CO_2 per year is estimated for this technology, assuming a capture potential of 95% of the total emissions of the cement industry (35).	
	Mitigation cost	1
	The abatement cost for this technology is estimated at 47 USD/tCO_2 (36).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	**Health and pollution reduction**	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	2
	The CO_2 capture process enhances the water demand of a cement plant for consumption, cooling and steam generation.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	**Impact on energy availability**	2
	There is an extra specific energy consumption for the capture process, though considerably smaller than the observed for the absorption-based CO_2 caputre (37).	
	Jobs and income generation	4
	A new value chain associated to CCS operations is expected to arise once industrial plants start to invest in this technology. That would induce the creation of new jobs.	
	Competitive advantages of the country	3
	Currently, there are no CCS projects in Brazilian cement plants. However, the Brazilian cement industry roadmap cites this technology as a possible way to reduce the emissions of this sector (3). Regarding oxyfuel, there is a pilot plant in Brazil at the FCC in a Petrobras refinery (39).	
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although there is a strategic axis specifically related to climate technologies (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC cites the promotion of new benchmarks of clean technologies and sustainable infrastructure as one of its measures (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF. However, one of the investment areas of the program is "sustainable infrastructure", which could include th CCS value chain (6).	
	Feasibility of adoption under the institutional framework	1
	There are many regulatory gaps in Brazil for CCS operations, especially regarding the stakeholder responsabilities in each phase of the productive structure (38). Besides, the country lacks a CO_2 transport structure for conecting sources to sinks (35). Also, there are no climate change mitigation policies in place to incentivise investment on CCS in Brazil.	

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MACRO-CRITERIA	INDICATOR	SCORE
CHEMICAL LOOPING (INDUSTRY/CEMENT)		
Technological	Technology Readiness	2
	The technology has currently a TRL 4 to 5 (34).	
	Mitigation potential	5
	A mitigation potential of 37,666 Gg CO_2 per year is estimated for this technology, assuming a capture potential of 95% of the total emissions of the cement industry (35).	
	Mitigation cost	1
	The abatement cost for this technology is estimated at 47 USD/tCO_2 (36).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	2
	The CO_2 capture process requires an extra consumption of water, cooling water and steam, increasing the plant's water demand. Thus, technology received a score of 2 in this criterion.	
	Impact on food production	4
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	2
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	2
	The CO_2 capture process enhances the water demand of a cement plant for consumption, cooling and steam generation.	
	Jobs and income generation	2
	A new value chain associated to CCS operations is expected to arise once industrial plants start to invest in this technology. That would induce the creation of new jobs.	
	Competitive advantages of the country	2
	Currently, there are no CCS projects in Brazilian cement plants. However, the Brazilian cement industry roadmap cites this technology as a possible way to reduce the emissions of this sector (3).	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although there is a strategic axis specifically related to climate technologies (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC cites the promotion of new benchmarks of clean technologies and sustainable infrastructure as one of its measures (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF. However, one of the investment areas of the program is "sustainable infrastructure", which could include th CCS value chain (6).	
	Feasibility of adoption under the institutional framework	1
	There are many regulatory gaps in Brazil for CCS operations, especially regarding the stakeholder responsabilities in each phase of the productive structure (38). Besides, the country lacks a CO_2 transport structure for connecting sources to sinks (35). Also, there are no climate change mitigation policies in place to incentivize investment on CCS in Brazil.	

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MACRO-CRITERIA	INDICATOR	SCORE
MEMBRANE SEPARATION (INDUSTRY/CHEMICAL)		
Technological	**Technology Readiness**	2
	The wide range of innovative membrane separation applications range from a TRL 3 to 5 (40).	
	Mitigation potential	1
	The mitigation potential is estimated at 1,351 Gg CO_2 per year, as a reduction of 8% of the chemical sector emissions (41).	
	Mitigation cost	1
	Due to the wide range of cost for this technology and low TRL, a conservative score 1 is attributed for this technology.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	**Health and pollution reduction**	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	5
	Currently, water treatment is the main application for this technology (41). Therefore, its development for other uses for more energy efficiency can promote improvements to the technology also for water treatment, by enhancing the membranes performance or reducing its costs.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	**Impact on energy availability**	4
	This technology aims to substitute energy intensive separation operations (40,41), which can save energy resources for other uses to the society.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	3
	The main inputs for membrane production are polymers from the petrochemical industry (42,43). Hence, the experienced petrochemical industry in Brazil would be able to supply a membrane production chain in the country. Also, there are important research centers in Brazil dedicated to develop technology for membrane separation, such as the Laboratório de Processos de Separação com Membranas e Polímeros (PAM), at COPPE/UFRJ. Nevertheless, the State-of-The-Art for commercial membrane separation technology products is currently in other countries, such as Germany and USA (43).	
Institutional	**Sinergias com a estratégia nacional de CTI 2016-2022**	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	3
	The need for frequent changes of the membranes due to the fast wear of the material (41) is a technical and economic barrier for the substitution of conventional separation processes by membranes.	

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MACRO-CRITERIA	INDICATOR	SCORE
	CATALYTIC CRACKING OF NAPHTHA (INDUSTRY/CHEMICAL)	
Technological	Technology Readiness	4
	According to (44), there is a demonstration plant for catalytic cracking of naphtha for the production of olefins in China, which gives the technology a TRL 8. Thus, the technology score is 4 for the indicator	
	Mitigation potential	1
	The mitigation potential estimated for this technology is 1,994 Gg CO_2 per year, as a reduction of 15% of the energy emissions in the chemical industry (41).	
	Mitigation cost	5
	This technology potentially reduce operational costs, since it enhances the energy efficiency of the process (45).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	The substitution of thermal cracking by a catalytic process reduces the emission of air pollutants (44).	
	Impact on water availability	4
	The substitution of the thermal cracking by a catalytic process reduce the demand of steam (44), which has a positive impact on the water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The energy efficiency gains related to this technology (41,44,45) can save energy resources for other uses to the society.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	3
	The State-of-The-Art plants with this technology are located in other countries. However, there are centers of excellence in Brazil for research and innovation in petrochemical industry, such as the Cenpes (Centro de Pesquisa e Desenvolvimento Leopoldo Américo Miguez de Mello) of Petrobras.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	3
	The technology licensors of this technology are still in pilot phase in Brazil and there is no perspective for its adoption in short term (41), which is a technical barrier and also a barrier for finance access.	

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MACRO-CRITERIA	INDICATOR	SCORE
	USE OF BIOMASS FOR OLEFIN PRODUCTION (INDUSTRY/CHEMICAL)	
Technological	Technology Readiness	5
	Braskem has a full-scale operating plant in Brazil for production of the so-called Green Ethylene, that uses sugarcane ethanol for the production of olefins (41,44).	
	Mitigation potential	2
	A mitigation potencial of 7,524 Gg CO_2 is estimated for this technology, as 2.4 tCO_2 captured per t of ethylene manufactured in Brazil (41).	
	Mitigation cost	2
	An abatement cost of 37 USD/tCO_2 is estimated for this technology (46).	
	Vulnerability to climate change	1
	Biomass growth can be severely impacted by climate change (31). Therefore, a biomass-based supply chain for producing olefins is more vulnerable to climate change than a fossil-based.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	1
	Agriculture is the sector that demands the highest share of water resources in Brazil (47). Therefore, a biomass-based olefins production chain should have a negative impact on water availability for other sectors.	
	Impact on food production	2
	Depending on the biomass used for production of olefins, a land or raw material competition with food production can occur (46).	
	Impact on biodiversity conservation	2
	Monoculture crops for producing olefins should affect negatively the biodiversity (48,49).	
Socio-economic	Impact on energy availability	2
	Despite using less fossil energy, the biomass-based process to produce olefins uses 3.5 to 5 times more energy than the fossil-based (44).	
	Jobs and income generation	4
	The Brazilian bioenergy sector is the world leader on number of jobs (32). Therefore, a biomass-based production of olefins should follow the same pattern and induce the creation of more jobs.	
	Competitive advantages of the country	5
	Brazil has good edaphoclimatic conditions for agriculture and is pioneer on mass production of biofuels (46). The country is also world leader on technology for production of ethylene from sugarcane ethanol (46).	
Institutional	Synergy with the country's National Strategy for ST&I	5
	Biomaterials production is explicitly cited on the document (4).	
	Synergies with national climate policies	5
	Guideline XV of the technical note for the RenovaBio program directly mentions the technology: "structuring measures for the development of new markets for biofuels, in addition to their energy (50).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The technology is not explicitly mentioned in the program, but there is a point of synergy with regard to technologies in bioenergy, in the strategic axis of sustainable infrastructure (6).	
	Feasibility of adoption under the institutional framework	4
	Brazil already has an industrial plant for the production of olefins from sugarcane ethanol, whose experience may serve as a precedent for other similar ventures for potential investors. However, the country lacks mechanisms to promote the appreciation of the environmental advantages of biomaterial in relation to the petrochemical product, allowing it to increase its competitiveness in the market (41).	

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MACRO-CRITERIA	INDICATOR	SCORE
USE OF H_2 OBTAINED FROM RENEWABLE SOURCES FOR THE PRODUCTION OF AMMONIA AND METHANOL (INDUSTRY/CHEMICAL)		
Technological	Technology Readiness	3
	The technology has a TRL 7 (9).	
	Mitigation potential	1
	A mitigation potential of 1,863 Gg CO_2 is estimated for this technology, as 100% of the process emissions from ammonia and methanol production in Brazil in the base year (41).	
	Mitigation cost	1
	According to ref (44), the extra cost of electricity for the production of ammonia from renewable H_2 can reach, in the worst case, up to 550 USD/t, with the proportion of process emissions from 1 tCO_2 to each ton produced of ammonia (with H_2 produced by the reform of natural gas). Thus, an abatement cost of 550 USD/t CO_2 is estimated.	
	Vulnerability to climate change	1
	Renewable energy sources are much more impacted by climate change than fossil energy (31). Thus, technology is more vulnerable to climate change than conventional practice.	
Physical	Health and pollution reduction	5
	The switch from steam reforming fossil fuels to renewable energy sources should positively impact air quality, as it eliminates emissions of air pollutants (51).	
	Impact on water availability	2
	Both the steam reforming process of natural gas and the electrolysis of water consume water in the chemical reaction to produce hydrogen gas. However, the stoichiometric ratio of water to hydrogen in electrolysis is double that for steam reform, which denotes, a priori, a higher consumption of water for the production of chemicals from renewable energy sources in relation to use of fossil fuels.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	2
	According to ref (41), the production of ammonia and methanol with H_2 obtained from renewable sources increases the energy demand in relation to conventional processes by 26 and 16 GJ/t of product, respectively.	
	Jobs and income generation	2
	The IRENA report on jobs in the renewable energy industry (32) shows that, on average, production chains based on renewable sources are more labor intensive compared to fossil resource chains. In addition, it is also qualitatively predicted by (51) a positive impact on the employment chain in substituting the production of ammonia and methanol via fossil fuels with electrolytic H_2 from renewable sources.	
	Competitive advantages of the country	2
	In terms of natural resources, Brazil has a privileged potential for wind and solar energy, which could be used to generate H_2 for the production of chemicals. However, in terms of national competence, it is highlighted by (52) that Brazilian investments in research on hydrogen technologies between 1999 and 2007 represented about one third of the resources invested individually by countries such as Russia, India, China and South Korea.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	3
	Technology is not explicitly mentioned in the text of the strategy, but there is a point of synergy with the strategic theme of the bioeconomy, in which initiatives referring to Renewable Chemistry are highlighted, that is, the production of chemicals using renewable energy sources (5).	
	Synergies with national climate policies	3
	Substitution of materials is pointed out in the PNMC as a mitigation option for the industrial sector, but in a generic way (21). The other climate policy instruments evaluated do not mention the replacement of materials.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not explicitly mentioned in the program, but there is a point of synergy with regard to technologies in bioenergy, in the strategic axis of sustainable infrastructure (6).	
	Feasibility of adoption under the institutional framework	2
	The generation of renewable H_2 in Brazil, aiming at the production of chemicals, faces the barrier that there are no national manufacturers of equipment for water electrolysis (52). In addition, the implementation of technology in the Brazilian industry would require investments in fixed capital, due to the replacement of the equipment currently installed (41).	

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MACRO-CRITERIA	INDICATOR	SCORE
	CO_2 CAPTURE IN AMMONIA PRODUCTION (INDUSTRY/CHEMICAL)	
Technological	Technology Readiness	5
	CO_2 separation is part of the conventional ammonia production process.	
	Mitigation potential	1
	A mitigation potential of 670 Gg CO_2 per year is estimated, as the liquid CO_2 emissions of the ammonia production (after using the gas to produce urea) (35).	
	Mitigation cost	4
	The abatement cost of this technology is under 5 USD/tCO_2 (35).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral on this criterion.	
	Jobs and income generation	4
	A new value chain associated to CCS operations is expected to arise once industrial plants start to invest in this technology. That would induce the creation of new jobs.	
	Competitive advantages of the country	2
	No CCS projects for ammonia plants in Brazil were found.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although there is a strategic axis specifically related to climate technologies (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC cites the promotion of new benchmarks of clean technologies and sustainable infrastructure as one of its measures (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF. However, one of the investment areas of the program is "sustainable infrastructure", which could include th CCS value chain (6).	
	Feasibility of adoption under the institutional framework	1
	There are many regulatory gaps in Brazil for CCS operations, especially regarding the stakeholder responsabilities in each phase of the productive structure (38). Besides, the country lacks a CO_2 transport structure for conecting sources to sinks (35). Also, there are no climate change mitigation policies in place to incentivise investment on CCS in Brazil.	

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MACRO-CRITERIA	INDICATOR	SCORE
STEAM REFORMING OF COKE OVEN GAS (INDUSTRY/IRON AND STEEL)		
Technological	Technology Readiness	3
	There is a pilot-scale plant of the South Korean company POSCO being developed for this technology (53).	
	Mitigation potential	3
	A mitigation potential of 12,685 Gg of CO_2 per year is estimated, as 30% of blast furnace emissions in Brazil (54).	
	Mitigation cost	1
	A precise abatement cost could not be estimated. Therefore, a conservative score of 1 is given to this technology on this indicator, due to its low technology readiness level.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	The reform of coke oven gases would reduce emissions of air pollutants (55,56).	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The use of a residual gas flow to produce a reducing agent for the process would substitute part of the coke demand. This would save energy resources for other uses to the society.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	1
	The state-of-the-art of this technology is currently developed in other countries, such as South Korea (53). No Brazilian research center currently studying this technology were found.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	1
	This technological change requires major changes in existing plants for retrofitting or the construction of new plants. That implies significant barriers regarding technology, financing and training for operation.	

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MACRO-CRITERIA	INDICATOR	SCORE
RECOVERY OF RESIDUAL HEAT FROM ELECTRIC ARC FURNACES USING THE ORGANIC RANKINE CYCLE (INDUSTRY/IRON AND STEEL)		
Technological	Technology Readiness	5
	There is a full-scale operational EAF steel plant equipped with ORC turbines for waste heat recovery in Riesa, Germany (57).	
	Mitigation potential	1
	A mitigation potential of 42 Gg CO_2 per year is estimated, considering the generation of 50 kWh of electricity per metric ton of steel (54) and a typical Brazilian grid emission factor of 0,1 tCO_2/MWh.	
	Mitigation cost	1
	A mitigation cost of 600 USD/t of CO_2 is found adapting the cost provided in ref (58) to a typical Brazilian grid emission factor of 0,1 t of CO_2 per MWh.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The use of waste heat to generate part of the electricity used in the process itself can save energy for other uses to the society (59).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	1
	The State-of-The-Art application for this technology is currently being developed in Germany (57). Also, no research projects in Brazilian research centers focused on this technology were identified.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	2
	Although the technology is proven in other countries, there no notice of its application in steel plants in Brazil. Thus, the lack of reference projects implies resistance on potential investors to be pioneers in the adoption of technology in the country, as well as the financing agencies to grant credit. In addition, the lack of local content of the technology hinders its development in the country, due to the dependence on imports of materials and assistance services.	

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MACRO-CRITERIA	INDICATOR	SCORE
	APPLICATION OF SIDERWIN PROCESS (INDUSTRY/IRON AND STEEL)	
Technological	Technology Readiness	2
	This technology is currently in a TRL 5 (9).	
	Mitigation potential	5
	A mitigation potential of 41,565 Gg CO_2 per year is estimated, as 87% of the Brazilian steel industry total emissions (9).	
	Mitigation cost	1
	A precise mitigation cost is not provided for this technology. Hence, due to its low TRL, a score 1 is given to this technology in this indicator.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	By replacing fossil fuels combustion with electricity, the technology contributes positively to reduce emissions of air pollutants.	
	Impact on water availability	2
	The consumption of water for the electrolysis process (52) should impact the availability of water for other sectors negatively.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	A reduction of 31% in the direct energy demand is achievable with this technology (60).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	1
	The State-of-The-Art for this technology is currently developed in other countries.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	1
	As it is a foreign technology, there is a need to import the technological package, which presents major bureaucratic problems, according to the vision of the Brazilian industrial sector (7). In addition, technological change involves the replacement of equipment installed in plants by an innovation, in addition to the exchange of the energy vector. This generates major changes in the way the plant operates, representing both financing and qualification barriers for operators who are qualified for the conventional process.	

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MACRO-CRITERIA	INDICATOR	SCORE
APPLICATION OF DRYING, PYROLYSIS AND COOLING (DPC) TECHNOLOGY IN CHARCOAL PRODUCTION (INDUSTRY/IRON AND STEEL)		
Technological	Technology Readiness	4
	This technology has a TRL 8 (61).	
	Mitigation potential	5
	A mitigation potential of 30,468 Gg CO_2 is estimated for this technology, as 75% of the emissions from pig iron production in Brazil (61).	
	Mitigation cost	5
	According to the economic analysis carried out in ref (61), the return on investment of a plant for the production of charcoal with DPC technology exceeds the same for a plant for the production of conventional charcoal.	
	Vulnerability to climate change	1
	As it is a technology that requires a renewable resource (biomass), the technology can be considered more vulnerable to the impact of climate changes compared to the use of mineral coal for the steel industry.	
Physical	Health and pollution reduction	4
	Charcoal production with technology produces less air pollutants than conventional technology (61).	
	Impact on water availability	2
	The demand for biomass as a raw material for the production of charcoal can negatively impact the availability of water for the rest of society (47).	
	Impact on food production	2
	The use of land for growing the biomass necessary for the production of charcoal can compete with food production (62).	
	Impact on biodiversity conservation	1
	The monoculture model for large-scale production of biomass has negative impacts on biodiversity (48,49).	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral on this criterion.	
	Jobs and income generation	4
	Since the Brazilian bioenergy chain is the world leader in terms of job creation (32), this technology should positively impact the generation of jobs and income.	
	Competitive advantages of the country	5
	It is a technology developed in Brazil for a situation that is peculiar to the country, with regard to the use of charcoal in large-scale steelmaking (61). In this sense, technology can be considered a local and specific solution for the Brazilian case.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not directly cited in the document. However, it is understood that there is a good synergy between technology and the strategy in terms of encouraging more sustainable biotechnologies, within the scope of the bioeconomy (4,61).	
	Synergies with national climate policies	4
	The technology is not mentioned directly in the documents considered, but all converge towards a more modern, efficient and sustainable use of bioenergetic resources, so that the technology can be considered synergistic with the objectives of the national climate policy guidelines (5,21,50)	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicitly mentioned in the program document. However, it can fit the concept of advanced bioenergy (6).	
	Feasibility of adoption under the institutional framework	4
	The replacement of the ovens currently employed by more modern technologies can be financed by credit lines available for forest financing, such as the ABC Florestas Program and the BNDES Climate Fund Program, which has a specific subprogram for financing efficient charcoal ovens (63). However, the lack of knowledge about the negative impacts on the environment of low efficiency furnaces and the distrust of the economics of more modern technologies by the producers stand out as barriers, in addition to the general low qualification of the workforce in the sector (61).	

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MACRO-CRITERIA	INDICATOR	SCORE
APPLICATION OF ONDATEC TECHNOLOGY IN CHARCOAL PRODUCTION (INDUSTRY/IRON AND STEEL)		
Technological	Technology Readiness	3
	According to (61), there is experience with technology in a small-scale operating environment, aimed at producing charcoal for domestic use, that is, TRL 7. Thus, the indicator was assigned a score of 3, based on the scale established.	
	Mitigation potential	5
	A mitigation potential of 30,468 Gg CO_2 is estimated for this technology, as 75% of the emissions from pig iron production in Brazil (61).	
	Mitigation cost	5
	According to the economic analysis carried out in ref (61), the return on investment of a plant for the production of charcoal with DPC technology exceeds the same for a plant for the production of conventional charcoal.	
	Vulnerability to climate change	1
	As it is a technology that requires a renewable resource (biomass), the technology can be considered more vulnerable to the impact of climate changes compared to the use of mineral coal for the steel industry.	
Physical	Health and pollution reduction	4
	Charcoal production with technology produces less air pollutants than conventional technology (61).	
	Impact on water availability	2
	The demand for biomass as a raw material for the production of charcoal can negatively impact the availability of water for the rest of society (47).	
	Impact on food production	2
	The use of land for growing the biomass necessary for the production of charcoal can compete with food production (62).	
	Impact on biodiversity conservation	1
	The monoculture model for large-scale production of biomass has negative impacts on biodiversity (48,49).	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral on this criterion.	
	Jobs and income generation	4
	Since the Brazilian bioenergy chain is at the forefront in terms of job creation (32), technology must positively impact the generation of jobs and income.	
	Competitive advantages of the country	5
	It is a technology developed in Brazil for a situation that is peculiar to the country, with regard to the use of charcoal in large-scale (61). In this sense, technology can be considered a local and specific solution for the Brazilian case, which qualifies the indicator to score 5.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not directly cited in the document. However, it is understood that there is a good synergy between technology and the strategy in terms of encouraging more sustainable biotechnologies, within the scope of the bioeconomy (4,61).	
	Synergies with national climate policies	4
	The technology is not mentioned directly in the documents considered, but all converge towards a more modern, efficient and sustainable use of bioenergetic resources, so that the technology can be considered synergistic with the objectives of the national climate policy guidelines (5,21,50)	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicitly mentioned in the program document. However, it can fit the concept of advanced bioenergy (6).	
	Feasibility of adoption under the institutional framework	4
	The replacement of the ovens currently employed by more modern technologies can be financed by credit lines available for forest financing, such as the ABC Florestas Program and the BNDES Climate Fund Program, which has a specific subprogram for financing efficient charcoal ovens (63). However, the lack of knowledge about the negative impacts on the environment of low efficiency furnaces and the distrust of the economics of more modern technologies by the producers stand out as barriers, in addition to the general low qualification of the workforce in the sector (61).	

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MACRO-CRITERIA	INDICATOR	SCORE
BLAST FURNACE GAS COLLECTION AND REFORMING USING THE IGAR PROCESS (INDUSTRY/IRON AND STEEL)		
Technological	Technology Readiness	1
	According to (9), there is still no consolidated data on the technology's TRL index, given its still little advanced stage of development. Thus, technology was assigned a score of 1 in the indicator.	
	Mitigation potential	2
	A mitigation potential of 7,789 Gg CO_2 is estimated for this technology, as 0.3 tCO_2 per metric ton of steel (64).	
	Mitigation cost	1
	A precise mitigation cost is not provided for this technology. Hence, due to its low TRL, a score 1 is given to this technology in this indicator.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The purpose of the technology is to reuse the gases from the blast furnace to replace part of the use of coal (coke) in the process of reducing the ore, reducing the consumption of the resource (9). Thus, it is understood that the increase in energy efficiency for the process obtained with technology is positive for the availability of energy to other sectors.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	1
	The technology has been developed in European countries. No Brazilian research groups that are currently working on the development of this technology have been identified.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	1
	This technological change requires major changes in existing plants for retrofitting or the construction of new plants. That implies significant barriers regarding technology, financing and training for operation.	

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MACRO-CRITERIA	INDICATOR	SCORE
APPLICATION OF THE HISARNA PROCESS FOR FUSION REDUCTION (INDUSTRY/IRON AND STEEL)		
Technological	Technology Readiness	3
	This technology has a TRL 7 (9).	
	Mitigation potential	5
	A mitigation potential of 38,221 Gg CO_2 per year is estimated, as 80% of the total steel industry emissions (9).	
	Mitigation cost	5
	According to (64–66), the reduction in the number of steps in the HIsarna steelmaking process allows for a reduction in investment and operating costs combined with the mitigation of GHG emissions. Thus, the abatement cost was considered negative for the technology.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	According to (67), the technology is capable of reducing emissions of particulate matter, nitrogen oxide and sulfur dioxide, which are air pollutants.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The technology reduces energy consumption by up to 20% compared to blast furnace steel production (67).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	1
	The technology derives from a European project focused on reducing GHG emissions in the steel industry, with patents currently belonging to the Tata Steel group (67). In Brazil, initiatives for the development of this technology have not been identified.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	There are no direct mentions to this technology on the National Strategy for ST&I, although one of the strategic axes in the document is energy efficiency in industry (4).	
	Synergies with national climate policies	3
	There are no direct mentions to this technology on the main Brazilian climate policy documents, although the NDC encourages the energy efficiency promotion in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	There are no direct mentions to this technology in the Brazil's Country Program for the GCF, although it mentions the promotion of energy efficiency in the industry (6).	
	Feasibility of adoption under the institutional framework	1
	The issue of intellectual property on technology can be considered an important barrier to the implementation of this technology in Brazil. In addition, as technology is ideally associated with CO_2 capture, barriers to the CCS chain (lack of regulation, recovery of captured CO_2 and lack of transport infrastructure for the gas) would also apply to this technology for a full exploitation of its mitigation potential.	

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MACRO-CRITERIA	INDICATOR	SCORE
INDUSTRY 4.0 (INDUSTRY/CROSS-SECTORAL)		
Technological	Technology Readiness	3
	The multiple technologies that build the concept of a fourth-generation industry are characterized by a continuous process of innovation and a short period for its obsolescence (68). Thus, a score of 3 was assigned to the indicator.	
	Mitigation potential	5
	A mitigation potential of 28,554 Gg CO_2 per year is estimated. It was considered that the potential reduction in the flow of materials and energy could reduce the total emissions of the industry by 15% (69–71).	
	Mitigation cost	5
	The possible efficiency gains in the use of materials and energy from industry 4.0 coupled with the mitigation of GHG emissions (71) represent an opportunity for negative abatement costs.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	The lower flow of materials represents an opportunity to reduce emissions of air pollutants (71).	
	Impact on water availability	4
	The greater efficiency in the use of materials represents an opportunity to reduce the use and consumption of water in industry (71).	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	Industry 4.0 technologies allow the optimization of energy use in manufacturing (70,71), which has a positive impact on energy availability for other sectors.	
	Jobs and income generation	4
	The technologies of industry 4.0 represent a considerable increase in capital productivity (69), which has an impact on the generation of value and an increase in income for society. With regard to job creation, there is much uncertainty about the impact of digital technologies on the labor market, but the end of existing professions and the emergence of new ones is expected (72).	
	Competitive advantages of the country	2
	There are important Brazilian initiatives that contribute to the innovation of production, to mention the technological parks of universities with business incubators, such as UFRJ, which houses the Brazilian Company for Industrial Research and Innovation (EMBRAPII). However, the sectors of Brazilian industry, in general, have low productivity and a low rate of innovation compared to the international average (69). Regarding production factors, which in this case can be understood as enabling technologies, the technologies produced in Brazil are made mainly by transnational companies, with technological and conceptual development taking place at their foreign headquarters. About the integration of technology in the industry, there are mainly developers of digital solutions in Brazil for specific problems, but there is a lack of large technological integration companies. For Startups, there is an important growing movement in Brazil with this trend, but they still do not enjoy much credibility for the application of their innovative products in large companies, which are skeptical about the dominance of Startups teams in relation to the complex bureaucratic processes that involve corporate operations in Brazil. The experience of SENAI as a support body for industry (69.73) counts positively for fostering the innovation environment in Brazilian industry (69.73).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	5
	One of the strategic themes highlighted in the document are converging and enabling technologies, with a focus on industry.	
	Synergies with national climate policies	3
	Technology is not mentioned directly in the documents considered for national climate policy, but it is understood that there is a brief point of synergy with the NDC, which includes the promotion of energy efficiency in industry (5).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	Industry 4.0 is not directly mentioned in the document of the Brazil Country Program for the GCF, but the promotion of energy efficiency in industry is mentioned, which denotes the existence of a minimal synergy of technology with the plan (6).	
	Feasibility of adoption under the institutional framework	2
	In Brazil, with regard to infrastructure, there is a bottleneck for the development of industry 4.0 regarding the limited scope of mobile and broadband networks, which require investments to allow the flow of information necessary for advanced manufacturing operations (73). In addition, the Brazilian institutional framework lacks the appropriate instruments to guarantee companies intellectual protection, minimum cybersecurity standards and access to personal data. These elements are seen as fundamental for the good functioning of the new industrial generation (73).	

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MACRO-CRITERIA	INDICATOR	SCORE
USE OF RENEWABLE SOURCES IN INDUSTRIAL PROCESSES (INDUSTRY/CROSS-SECTORAL)		
Technological	Technology Readiness	4
	This measure comprises several technologies, in different states of maturity, from the use of solar energy for heating, technologically dominated, to the gasification of biomass for local electrical generation, which still requires learning. Thus, the indicator received a score of 4.	
	Mitigation potential	5
	A mitigation potential of 28,554 Gg CO_2 per year is calculated. The potential to reduce 40% of the industry's energy emissions by replacing fossil resources with renewable sources was considered (35).	
	Mitigation cost	3
	In the list of industrial technologies supplied by renewable sources, there are different ranges of abatement costs. For example, the use of solar collectors for heating water in the food and beverage industry has a lower cost than heating with fuels, that is, a negative abatement cost (74), while the use of biogas in the ceramic industry should cost a little more than natural gas (75). On the other hand, the generation of local electricity from renewable sources (wind, solar or biomass power plant) to supply the demands of mining processes must have considerably higher costs than the supply through the electricity grid (76). Thus, a score of 3 was assigned to the indicator, in order to cover the different uses of renewable sources by industries in their multiple cost ranges.	
	Vulnerability to climate change	1
	The effects of climate change have a much more severe impact on renewable energy sources, causing them to increase their variability and, consequently, risk (31). Therefore, when using renewable sources, industrial processes introduce a climate element of risk in their supply chain.	
Physical	Health and pollution reduction	4
	In general, the transition from the use of fossil sources to modern renewables, especially for energy, is beneficial to air quality by reducing emissions of local air pollutants (77).	
	Impact on water availability	4
	According to (78), the adoption of renewable sources can also benefit the water supply, mainly by reducing events such as acid rain or acid mine drainage (in the case of coal), which contaminate water bodies.	
	Impact on food production	2
	Sites for use of renewable energy sources can occupy large areas, changing the dynamics of land use. Especially for bioenergy, there is a debate about the possibility of competition for the use of land for the production of food or energy (62).	
	Impact on biodiversity conservation	2
	Changes in the dynamics of land use caused by pressure from large-scale renewable energy projects, which occupy large areas, can impact biodiversity. An emblematic example is the impacts of wind farms on bird ecosystems (79). In the case of bioenergy, the biomass production model with large areas of monocultures also represents a significant impact on biodiversity (48,49).	
Socio-economic	Impact on energy availability	4
	The use of renewable sources available locally to replace fossil sources, finite by definition, positively impacts the availability of energy either for other sectors or for future generations (78).	
	Jobs and income generation	4
	According to (32), renewable energy production chains are more labor intensive than fossil chains. Thus, the increased use of renewable sources in the industry should have a positive impact in terms of job and income generation.	
	Competitive advantages of the country	5
	In terms of production factors, Brazil has a privileged energy potential of renewable resources, as well as a supply chain already established for the use of renewable resources. As for labor, Brazil stands out as one of the countries that employs the most people in the renewable energy production chain, especially in the bioenergy sector (32). The country also stands out in terms of national competence, having its energy matrix with a share of renewables much higher than the global average (80) and successful experiences with public policies to stimulate the use of the country's renewable resources (eg: PROÁLCOOL, PNPB and PROINFA). However, the low average rate of innovation in the Brazilian industrial sector (69) may limit the use of the country's positive conditions for the industrial use of renewable resources.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	There is no specific mention in the document on the use of renewable sources specifically in the industry, but the use of renewable sources, generically, is a topic of great relevance to the program.	
	Synergies with national climate policies	4
	There is no specific mention of the adoption of renewable sources in industry, but the plans that make up climate policies have the use of renewable sources as one of the central elements. Thus, the technology presents a good synergy with Brazil's climate policies.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	There is no specific mention for the adoption of renewable sources in the industry, but there is a citation to the promotion of clean technologies in the industry in the strategic axis "Sustainable Infrastructure", which denotes a good synergy between technology and the plan.	
	Feasibility of adoption under the institutional framework	3
	In Brazil, the historical experience of using renewable energy and centralized planning of the energy sector has built a complex and robust regulatory framework for the energy market, with specific rules for each segment of the production chain (generation, transmission and distribution) according to your characteristics. On the financing side, there are several financial products available in the credit market in Brazil aimed at renewable energy projects in the industry, such as "Energias Renováveis" and "Fundo Clima" of BNDES, "FNE Solar" of Banco do Nordeste, Itaú's "Linha BID" and Santander "CDC Sustentável" (81). However, there are barriers to the advancement of renewable energies in the industry of various natures, of which the financial risk associated with the high time and transaction costs to access financing, the intermittency (solar and wind) and the associated climatic risks for supply stand out. This is aggravated by the difficulty of storage, the lack of infrastructure to connect to the grid in many places with good generation potential and the lack of dissemination of information about places with good potential for using renewable sources.	

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MACRO-CRITERIA	INDICATOR	SCORE
TRANSPORT OF CO_2 (INDUSTRY/CROSS-SECTORAL)		
Technological	Technology Readiness	4
	The transport of CO_2 by different modes is a technologically mature operation. It has been used for decades in the USA, for example, for advanced oil recovery, mainly by pipeline modal (35).	
	Mitigation potential	5
	A mitigation potential of 76,310 Gg CO_2 per year is estimated. It represents 90% of total industry emissions in the base year, a value associated with CCS systems (35).	
	Mitigation cost	2
	The cost of transporting CO_2 depends significantly on the volume transported and the distance between the source and the destination (35). An analysis of a new optimized CO_2 transport network proposed to collect CO_2 from ethanol distilleries in south-central Brazil and use gas for advanced oil recovery in offshore fields found transportation costs ranging between 32 and 87 USD per metric ton of CO_2 (82).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	2
	It is necessary to consider a high energy expenditure in the initial compression stage and in the gas recompression stations necessary along the duct section (35). In the case of road or waterway transport, fuel consumption for the movement of CO_2 must be considered (35,82). Thus, the stage of transporting CO_2 from the source to the final destination is necessarily associated with energy consumption, which negatively impacts the availability of energy to other sectors of society.	
	Jobs and income generation	4
	The development of a pipeline network as an infrastructure for CO_2 transport should stimulate the generation of several jobs (83). For the case of road or waterway transport, jobs associated with the operation of vehicles can also be generated.	
	Competitive advantages of the country	2
	Brazil lacks a pipeline infrastructure for transporting CO_2, requiring a large amount of capital to build a network dedicated to the operation of CCS. However, it should be noted that even the natural gas transportation network in Brazil is incipient, covering a low portion of the national territory and with expansion projects stopped due to lack of investment. Petrobras' experience in the construction of gas pipelines can count positively for Brazil, since the company may be interested in collecting CO_2 for use in its oil production activities.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	The technology is not directly mentioned in the strategy document, but there is a point of synergy with the strategic theme "climate" (4).	
	Synergies with national climate policies	3
	The Brazilian NDC cites the promotion of new standards of clean technologies and sustainable infrastructure in the industrial sector as one of its measures (5), which may include the CCS chain.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not directly mentioned in the document, but a strategic axis of sustainable infrastructure is verified (6), which could include the CCS chain.	
	Feasibility of adoption under the institutional framework	1
	In Brazil, currently, there are several regulatory gaps in the CCS chain, especially in the allocation of responsibility for gas at each stage of the production structure (38). In addition, there is no CO_2 transport infrastructure in Brazil, which impairs the gas logistics process (35). There are also no policies to encourage the mitigation of emissions in force, which makes the operation a burden with no return for investors.	

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MACRO-CRITERIA	INDICATOR	SCORE
STORAGE OF CO_2 (INDUSTRY/CROSS-SECTORAL)		
Technological	Technology Readiness	5
	The geological storage of CO_2 is a technologically mature industrial operation. It has been used for decades in the USA, for example, for advanced oil recovery in mature fields (35).	
	Mitigation potential	5
	A mitigation potential of 76,310 Gg CO_2 per year is estimated. It represents 90% of total industry emissions in the base year, a value associated with CCS systems (35).	
	Mitigation cost	3
	According to (84), the costs for CO_2 injection into oil wells vary between 7 and 11 USD per metric ton of CO_2.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	3
	On the one hand, CO_2 storage requires an increase in pressure above that established for the transport stage, which represents an additional energy demand for compression. However, the use of gas for advanced oil recovery increases the potential for oil production in mature fields, which is positive for the availability of energy to the population. Thus, the impact of this technology is considered neutral on this indicator.	
	Jobs and income generation	2
	The use of CO_2 storage technology should induce the development of a value chain for associated activities, in the concept of "Green Jobs" (83).	
	Competitive advantages of the country	5
	In terms of production factors, Brazil is a major oil producer globally, has qualified labor and an oil and gas industry established and prepared to operate with this technology. Under national competence, Petrobras already has a CCS installation in operation in the Santos Basin, storing CO_2 in the pre-salt layer (85). There are also experiences in CO_2 injection in onshore fields in the Recôncavo Basin (86).	
Institutional	Synergy with the country's National Strategy for ST&I	3
	Technology is not directly mentioned in the strategy document, but there is a point of synergy with the strategic theme "climate" (4).	
	Synergies with national climate policies	3
	The Brazilian NDC cites the promotion of new standards of clean technologies and sustainable infrastructure in the industrial sector as one of its measures (5), which may include the CCS chain.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not directly mentioned in the document, but a strategic axis of sustainable infrastructure is verified (6), which could include the CCS chain.	
	Feasibility of adoption under the institutional framework	1
	In Brazil, currently, there are several regulatory gaps in the CCS chain, especially in the allocation of responsibility for gas at each stage of the production structure (38). In addition, there is no CO_2 transport infrastructure in Brazil, which impairs the gas logistics process (35). There are also no policies to encourage the mitigation of emissions in force, which makes the operation a burden with no return for investors.	

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MACRO-CRITERIA	INDICATOR	SCORE
	IMPLEMENTATION OF FLARE PILOTS (ENERGY/OIL AND GAS E&P)	
Technological	Technology Readiness	5
	The technology is mature, with technology readiness level score 9. Several Norwegian platforms already operate using flare pilot ignition systems.	
	Mitigation potential	1
	By eliminating constant flare emissions, flare pilot ignition systems can avoid emissions of up to 250 $ktCO_2eq$ per year (1).	
	Mitigation cost	2
	Mitigation costs of approximately 50 USD/tCO_2 (1).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	Flare pilot ignition systems reduce the burning of natural gas in the platform, resulting in health benefits for the workers operating these units.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	By eliminating constant flare emissions, this technology increases the availability of natural gas (2).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	3
	The technology is considered neutral on this criterion.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the document highlights the importance of the oil and gas industry for the country, as well as the need for its activities to be developed in a safe, sustainable and environmentally responsible way.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by national climate policies. However, national climate policies encompass, in a broader sense, the reduction of emissions related to E&P in the oil and gas industry.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	5
	The E&P segment in the oil and gas industry is a well-established regulated segment in Brazil. In terms of regulation, a New Regulation Framework for Oil and Gas has been enforced in 2010 (PLC n°08/2010).	

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MACRO-CRITERIA	INDICATOR	SCORE
INSTALLATION OF STEAM RECOVERY UNITS IN STORAGE TANKS (ENERGY/OIL AND GAS E&P)		
Technological	Technology Readiness	5
	The technology is mature, with technology readiness level index 9.	
	Mitigation potential	1
	The installation of vapor recuperation units in storage tanks aims at avoiding the emission of light hydrocarbons, such as methane, volatile organic compounds and natural gas liquids. In this context, this technology is estimated to avoid up to 215 ktCO_2eq per year (1).	
	Mitigation cost	4
	Mitigation costs of 3.1 to 3.4 USD/tCO_2 (1).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	The installation of vapor recuperation units in storage tanks reduces the burning of natural gas in the platform, resulting in health benefits for the workers operating these units.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	By reducing the losses of natural gas in crude oil storage tanks, this technology increases the availability of natural gas (2).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	3
	The technology is considered neutral on this criterion.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the document highlights the importance of the oil and gas industry for the country, as well as the need for its activities to be developed in a safe, sustainable and environmentally responsible way.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by national climate policies. However, national climate policies encompass, in a broader sense, the reduction of emissions related to E&P in the oil and gas industry.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	4
	The E&P segment in the oil and gas industry is a well-established regulated segment in Brazil. In terms of regulation, a New Regulation Framework for Oil and Gas has been enforced in 2010 (PLC nº08/2010).	

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MACRO-CRITERIA	INDICATOR	SCORE
	GAS-TO-LIQUIDS (ENERGY/OIL AND GAS E&P)	
Technological	Technology Readiness	3
	The technology readiness level index is estimated to be 6, since there are still no demonstration plants. Nonetheless, it is worth noting that Petrobras, in partnership with CompactGTL (CGTL), has built a pilot plant with the capacity to process 200.000 scf/day. The plant is located in Aracaju (SE) and began its operation in 2010 (3).	
	Mitigation potential	1
	By reducing flaring to the minimum amount needed for safety, this technological route has an estimated mitigation potential of up to 255 kt CO_2eq per year (1).	
	Mitigation cost	1
	High mitigation costs: approximately 217 USD/tCO_2 (1).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	4
	This technological route reduces the burning of natural gas in the platform, resulting in health benefits for the workers operating these units.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	5
	By reducing the burning of natural gas, this technological route contributes positively to energy availability, using the available natural gas for the production of synthetic fuels.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and required skilled labor.	
	Competitive advantages of the country	4
	There are competitive advantages for Brazil, since Brazil is a major producer of natural gas. The deployment of this technological route would reduce natural gas losses, using the surplus in natural gas for the production of synthetic fuels. As previously mentioned, Petrobras, in partnership with CGTL, has built a pilot plant for the conversion of natural gas into synthetic liquids, in Aracaju (SE). Additionally, there are lines of research dedicated to this subject at Petrobras' Research Center (Cenpes/Petrobras) and at the School of Chemistry, of the Federal University of Rio de Janeiro (EQ/UFRJ).	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the document highlights the importance of the oil and gas industry for the country, as well as the need for its activities to be developed in a safe, sustainable and environmentally responsible way.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by national climate policies. However, national climate policies encompass, in a broader sense, the reduction of emissions related to E&P in the oil and gas industry.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	1
	The E&P segment in the oil and gas industry is a well-established regulated segment in Brazil. However, there are no legal instruments in place for the deployment of this technological route.	

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MACRO-CRITERIA	INDICATOR	SCORE
CO_2 CAPTURE IN THE PRODUCTION OF OIL AND NATURAL GAS (ENERGY/OIL AND GAS E&P)		
Technological	Technology Readiness	1
	The technology readiness level index regarding CO_2 capture systems using membranes is estimated to be 3, indicating the technology to be still at the point of proof-of-concept (4).	
	Mitigation potential	2
	The mitigation potential of CO_2 capture systems using membranes in the oil and gas production is estimated at approximately 6,000 ktCO_2eq per year (1).	
	Mitigation cost	3
	Mitigation costs of 21 USD/tCO_2 (1).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	Even if this technology reduces GHG emissions at a global scale, it does not directly affect the pollution and consequent health problems at a local scale.	
	Impact on water availability	2
	CO_2 capture systems are water demanding systems, resulting in negative impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	1
	CO_2 capture systems are highly energy intensive systems. The related energy penalties result in significant impacts on energy availability.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and required skilled labor.	
	Competitive advantages of the country	4
	There are competitive advantages for Brazil, since Brazil is a major producer of oil and natural gas. The reduction of GHG emissions related to the oil and gas industry would benefit the country's energy sector by promoting activities in higher consonance with sustainable environmental parameters. In what regards R&D, COPPE/UFRJ, EQ/UFRJ, RCGI/USP and Cenpes/Petrobras all have innovative lines of research dedicated to CO_2 capture using membranes.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the document highlights the importance of the oil and gas industry for the country, as well as the need for its activities to be developed in a safe, sustainable and environmentally responsible way.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by national climate policies. However, national climate policies encompass, in a broader sense, the reduction of emissions related to E&P in the oil and gas industry.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	1
	The oil and gas industry is a well-established regulated segment in Brazil. However, there are no legal instruments in place for the deployment of this technological route, especially in what regards transportation and storage of the carbon captured.	

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MACRO-CRITERIA	INDICATOR	SCORE
	CO_2 CAPTURE IN FLUID CATALYTIC CRACKING UNITS (ENERGY/OIL REFINING)	
Technological	Technology Readiness	2
	In fluid catalytic cracking units, CO_2 is usually captured through oxycombustion. The technology readiness level index of oxy-combustion systems for CO_2 capture is 4 (4).	
	Mitigation potential	2
	The mitigation potential of CO_2 capture systems in fluid catalytic cracking units is approximately 7,600 ktCO_2eq per year (1).	
	Mitigation cost	2
	Mitigation costs of 74 USD/tCO_2 (5).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	Even if this technology reduces GHG emissions at a global scale, it does not directly affect the pollution and consequent health problems at a local scale.	
	Impact on water availability	1
	CO_2 capture systems are highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	1
	CO_2 capture systems are highly energy intensive systems. The related energy penalties result in significant impacts on energy availability.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and required skilled labor.	
	Competitive advantages of the country	4
	There are competitive advantages for Brazil, since Brazil is a major producer of oil and natural gas, having an important oil refining park. The deployment of CO_2 capture systems in the oil refining segment would be beneficial to the country's energy sector by reducing GHG emissions and promoting activities in higher consonance with sustainable environmental parameters. In what regards R&D, COPPE/UFRJ has innovative lines of research dedicated to CO_2 capture through oxycombustion. Furthermore, the technology is currently being tested by Cenpes/Petrobras, in a prototype fluid catalytic cracking unit, at the Shale Industrialization Business Unit (SIX), Paraná (6).	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the document highlights the importance of the oil and gas industry for the country, as well as the need for its activities to be developed in a safe, sustainable and environmentally responsible way.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by national climate policies. However, national climate policies encompass, in a broader sense, the reduction of emissions related to E&P in the oil and gas industry.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	1
	The oil and gas industry is a well-established regulated segment in Brazil. However, there are no legal instruments in place for the deployment of this technological route, especially in what regards transportation and storage of the carbon captured.	

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MACRO-CRITERIA	INDICATOR	SCORE
CO_2 CAPTURE IN HYDROGEN GENERATION UNITS (ENERGY/OIL REFINING)		
Technological	Technology Readiness	5
	In hydrogen generation units, CO_2 is typically captured through chemical absorption processes with amines. Chemical absorption processes are mature, with technology readiness level index 9 (4).	
	Mitigation potential	1
	The mitigation potential of CO_2 capture systems in hydrogen generation units is approximately 880 kt CO_2eq per year (1).	
	Mitigation cost	2
	Mitigation costs of 71 USD/tCO_2 (5).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	Even if this technology reduces GHG emissions at a global scale, it does not directly affect the pollution and consequent health problems at a local scale.	
	Impact on water availability	1
	CO_2 capture systems are highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	1
	CO_2 capture systems are highly energy intensive systems. The related energy penalties result in significant impacts on energy availability.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and required skilled labor.	
	Competitive advantages of the country	4
	There are competitive advantages for Brazil, since Brazil is a major producer of oil and natural gas, having an important oil refining park. The deployment of CO_2 capture systems in the oil refining segment would be beneficial to the country's energy sector by reducing GHG emissions and promoting activities in higher consonance with sustainable environmental parameters. In what regards R&D, COPPE/UFRJ has innovative lines of research dedicated to CO_2 capture through chemical absorption.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the document highlights the importance of the oil and gas industry for the country, as well as the need for its activities to be developed in a safe, sustainable and environmentally responsible way.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by national climate policies. However, national climate policies encompass, in a broader sense, the reduction of emissions related to E&P in the oil and gas industry.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	1
	The oil and gas industry is a well-established regulated segment in Brazil. However, there are no legal instruments in place for the deployment of this technological route, especially in what regards transportation and storage of the carbon captured.	

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MACRO-CRITERIA	INDICATOR	SCORE
	HYDROKINETIC TURBINES (ENERGY/ELECTRIC)	
Technological	Technology Readiness	3
	Technology readiness level index 6. The University of Brasilia (UnB) is working in partnership with Eletronorte in Project Tucunaré, for the development of a hydrokinetic turbine of 100 kW, with 5 m diameter (7).	
	Mitigation potential	1
	Considering a market penetration rate of 1.7% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 1,209 kt CO_2eq per year (8,9).	
	Mitigation cost	4
	Mitigation costs of 7 USD/tCO_2 (10).	
	Vulnerability to climate change	2
	Climate change can affect water availability. Therefore, the technology can be affected by climate change.	
Physical	Health and pollution reduction	4
	The technology can positively contribute to the reduction of pollution and health benefits by substituting fossil fuels in the power sector.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	5
	The usage of residual kinetic energy related to water flows coming from conventional hydroelectric power plants turbines results in gains of up to 5% of installed power (11).	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs for the construction and installation of hydrokinetic turbines.	
	Competitive advantages of the country	5
	There are competitive advantages for Brazil, since Brazil has significant hydropower potential and hydrokinetic turbines may improve the harnessing of this potential. In terms of R&D, the University of Brasilia (UnB) is working in partnership with Eletronorte in Project Tucunaré, for the development of a 100 kW hydrokinetic turbine (7). Furthermore, COPPE/UFRJ, UNIFEI, and Cepel/Eletrobras are currently working on innovative research regarding hydrokinetic turbines.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, strategies point towards the development of a higher share of renewables in the national energy matrix.	
	Synergies with national climate policies	4
	The technology is not explicitly mentioned by national climate policies. However, national climate policies highlight the need for expanding the share of renewables and enhancing harness of hydropower generation.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The technology is not explicitly mentioned by the Country Programme Brazil for the Green Climate Fund. However, renewable energy figures among the main thematic axes and investment segments proposed by the programme.	
	Feasibility of adoption under the institutional framework	3
	Up to this moment, there is no information regarding legal instruments to promote this technology. Nonetheless, there are incentives in place to encourage research and development of this technological route, as exemplified by the partnership between UnB and Eletrobras Eletronorte.	

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MACRO-CRITERIA	INDICATOR	SCORE
	REVERSIBLE HYDROELECTRIC PLANTS (ENERGY/ELECTRIC)	
Technological	Technology Readiness	5
	The technology is mature, with technology readiness level index 9.	
	Mitigation potential	1
	Considering a market penetration rate of 0.23% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 164 $ktCO_2eq$ per year (8,9).	
	Mitigation cost	4
	Mitigation costs of 6.80 USD/tCO_2 (10).	
	Vulnerability to climate change	2
	Climate change can affect water availability. Therefore, the technology can be affected by climate change.	
Physical	Health and pollution reduction	4
	The technology can positively contribute to the reduction of pollution and health benefits by substituting fossil fuels in the power sector.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	5
	Pumped-storage hydroelectricity can provide systemic benefits by supporting the expansion of run-of-the-river hydroelectricity, improving system reliability and quality of energy supply. The stored energy can be readily used in contingency situations (12).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	5
	There are competitive advantages for Brazil, since Brazil has significant hydropower potential. Pumped-storage hydroelectricity systemic benefits include the support of run-of-the-river hydroelectricity expansion and improvements in system reliability and quality of energy supply. In terms of R&D, COPPE/UFRJ and Cepel/Eletrobras have innovative lines of research dedicated to this topic. For instance, COPPE/UFRJ is conducting research regarding the analysis of most appropriate sites for placing pumped-storage hydroelectricity plants.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, strategies point towards the development of a higher share of renewables in the national energy matrix.	
	Synergies with national climate policies	4
	The technology is not explicitly mentioned by national climate policies. However, national climate policies highlight the need for expanding the share of renewables and enhancing harness of hydropower generation.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicitly mentioned by the Country Programme Brazil for the Green Climate Fund. However, renewable energy figures among the main thematic axes and investment segments proposed by the programme. Furthermore, the programme mentions energy storage, focused on renewable energy.	
	Feasibility of adoption under the institutional framework	2
	Up to this moment, there is no information regarding legal instruments to promote this technology.	

continues

continuation

MACRO-CRITERIA	INDICATOR	SCORE
REPOWERING HYDROELECTRIC PLANTS (ENERGY/ELECTRIC)		
Technological	Technology Readiness	5
	The technology is mature, with technology readiness level index 9.	
	Mitigation potential	1
	Considering a market penetration rate of 0.25% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 178 $ktCO_2eq$ per year (8,9).	
	Mitigation cost	4
	Mitigation costs of 1 USD/tCO_2 (10).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	Repowering of hydropower plants can deliver gains in power and yield from 2.5% to 20% of the installed capacity. Additionally, repowering promotes the recovery of actual power lost throughout the years, increasing equipment availability. This leads to higher capacity factors, resulting in gains in yields, free falls, turbine flows, and availability (13).	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive advantages of the country	5
	There are competitive advantages for Brazil, since Brazil has significant hydropower potential and repowering hydropower plans can enhance this potential. In terms of R&D, COPPE/UFRJ, UNIFEI, and Cepel/Eletrobras have innovative lines of research in this field.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, strategies point towards the development of a higher share of renewables in the national energy matrix.	
	Synergies with national climate policies	4
	The technology is not explicitly mentioned by national climate policies. However, national climate policies highlight the need for expanding the share of renewables and enhancing harness of hydropower generation.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The technology is not explicitly mentioned by the Country Programme Brazil for the Green Climate Fund. However, renewable energy figures among the main thematic axes and investment segments proposed by the programme.	
	Feasibility of adoption under the institutional framework	2
	Up to this moment, there is no information regarding legal instruments to promote this technology.	

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MACRO-CRITERIA	INDICATOR	SCORE
	OFFSHORE WIND POWER (ENERGY/ELECTRIC)	
Technological	Technology Readiness	1
	This technology is currently under initial stages of development, with technology readiness level index 3 (14).	
	Mitigation potential	1
	Considering a market penetration rate of 0.4% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 284 kt CO_2eq per year (8),(9).	
	Mitigation cost	1
	Costs related to offshore wind power are relatively high. In general, the offshore environment is severe and requiring that equipments, including both wind turbines and floating structures, are built in order to withstand such adverse conditions. In this context, costs for equipments, foundations, installation and transport of structures, as well as additional costs for connecting the generation site to the energy transmission and distribution network, are significantly high.	
	Vulnerability to climate change	2
	Climate change can affect wind patterns and influence dry and wet seasons (which ultimately also affects wind patterns). Therefore, offshore wind power generation can be affected by climate change.	
Physical	Health and pollution reduction	4
	The technology can positively contribute to the reduction of pollution and health benefits by substituting fossil fuels in the power sector.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	2
	Offshore wind power may affect marine life, especially marine mammals, which are. More sensitive to sound impacts from structure installation phases. Furthermore, offshore wind power can affect bird species through the risk of collision, barrier effect (altering their migration routes), loss of habitat and attraction risk (15).	
Socio-economic	Impact on energy availability	5
	Offshore wind power has significant positive impacts on energy availability.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs for the construction and installation of wind turbines and floating structures.	
	Competitive advantages of the country	5
	There are competitive advantages for Brazil, since Brazil has significant offshore wind power potentials. In terms of R&D, COPPE/UFRJ, INPE, and Cepel/Eletrobras have innovative lines of research in this fiels. Furthermore, Petrobras in partnership with Universidade Federal do Rio Grande do Norte (UFRN), Universidade Federal de Juiz de For a (UFJF) and Universidade Federal do Rio de Janeiro (UFRJ) are mapping offshore wind power potentials in the Brazilian coast (16).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified since the strategies reinforce the importance of wind power development.	
	Synergies with national climate policies	4
	The technology is not explicitly mentioned by national climate policies. However, national climate policies highlight the need for expanding the share of renewables and the incentives to wind power generation.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The Country Programme Brazil for the Green Climate Fund emphatically points towards the development of renewable energy, explicitly mentioning wind power generation, as a priority to the diversification of the national energy matrix. Renewables figure not only as a mitigation option, but effectively contribute to the enhancement of economic resilience and energy security.	
	Feasibility of adoption under the institutional framework	3
	Up to this moment, there is no regulatory framework for offshore wind power in Brazil. However, the Natural Resources and Energy Strategy Center has formed a commission (Executive Commission for the Promotion of a Regulatory Framework of Brazilian Offshore Wind Power) to discuss multi-institutional aspects and to elaborate studies in order to develop a regulatory framework for exploring offshore wind power in the country.	

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MACRO-CRITERIA	INDICATOR	SCORE
INTEGRATED COMBINED CYCLE WITH BIOMASS GASIFICATION IN THERMOELECTRIC PLANTS (ENERGY/ELECTRIC)		
Technological	Technology Readiness	3
	This technology is currently in demonstration stages, with technology readiness level index 6-7.	
	Mitigation potential	1
	Considering a market penetration rate of 4.0% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 2,844 kt CO_2eq per year (8,9).	
	Mitigation cost	2
	Mitigation costs of 45 USD/tCO_2 (17).	
	Vulnerability to climate change	2
	Climate change may affect biomass and water availability, directly influencing land use. Furthermore, the efficiency of thermal machines can be impacted by climate change.	
Physical	Health and pollution reduction	4
	The technology can positively contribute to the reduction of pollution and health benefits by substituting fossil fuels in the power sector.	
	Impact on water availability	1
	The use of biomass for thermoelectric generation may negatively impact water availability, since both biomass production and the thermodynamic cycle are water intensive.	
	Impact on food production	1
	The use of biomass for thermoelectric generation may negatively impact food production by the shifting the use of biomass from food production to energy generation. Additionally, land use and land use change aspects might also affect food production.	
	Impact on biodiversity conservation	1
	Energy dedicated crops may negatively impact biodiversity, especially if agro ecological zoning is not respected.	
Socio-economic	Impact on energy availability	4
	The use of renewable resources such as biomass and the possibility of using agricultural and forestry residues represent an important step in the diversification of the energy matrix, positively contributing the energy availability.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and the need for skilled labor for the construction and installation of equipments, and for the operation of the power plant.	
	Competitive advantages of the country	5
	Brazil is a major producer and consumer of bioenergy. There are significant competitive advantages to the expansion of biomass use, especially when considering agricultural and forestry residues. In terms of R&D, COPPE/UFRJ, UNICAMP, USP, and Cenpes/Petrobras have innovative lines of research in this field.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified due to the importance of bioenergy as an alternative to the ostensive use of fossil fuels, aiding in the reduction of GHG emissions, as well as other compounds that are harmful to human health.	
	Synergies with national climate policies	4
	The technology is not explicitly mentioned by national climate policies. However, national climate policies highlight the need for expanding the share of renewables and the incentives to bioenergy.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicitly mentioned by the Country Programme Brazil for the Green Climate Fund. However, renewable energy figures among the main thematic axes, along with the need to prioritize incentives to bioenergy technologies, as well as mechanisms to improve the feasibility of biomass-based power generation.	
	Feasibility of adoption under the institutional framework	3
	The Programme of Incentive to Alternative Sources of Energy (Programa de Incentivo às Fontes Alternativas de Energia – PROINFA) has been instituted by law with the objective of enhancing the participation of energy generation from renewable resources, including bioenergy.	

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MACRO-CRITERIA	INDICATOR	SCORE
CONCENTRATED SOLAR POWER (ENERGY/ELECTRIC)		
Technological	Technology Readiness	4
	There are demonstration plants in operation worldwide. In the Brazilian context, several projects are currently under implementation, such as the SMILE project for the construction of two concentrated solar power units, one in Pirassununga, São Paulo, and another in Caiçara do Rio do Vento, Rio Grande do Norte; and Petrobras' project in partnership with CTGAS-ER, Universidade Federal de Santa Catarina (UFSC) and Universidade Federal do Rio Grande do Norte (UFRN), to build a 3 MW CSP plant in Vale do Açu, Rio Grande do Norte.	
	Mitigation potential	2
	Considering a market penetration rate of 9.8% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 6,967 kt CO_2eq per year (8),(9).	
	Mitigation cost	1
	Mitigation costs of 145 USD/tCO_2 (10).	
	Vulnerability to climate change	2
	Climate change may affect biomass and water availability, directly influencing land use. Furthermore, the efficiency of thermal machines can be impacted by climate change.	
Physical	Health and pollution reduction	4
	The technology can positively contribute to the reduction of pollution and health benefits by substituting fossil fuels in the power sector.	
	Impact on water availability	1
	The use of biomass for thermoelectric generation may negatively impact water availability, since both biomass production and the thermodynamic cycle are water intensive.	
	Impact on food production	1
	The use of biomass for thermoelectric generation may negatively impact food production by the shifting the use of biomass from food production to energy generation. Additionally, land use and land use change aspects might also affect food production.	
	Impact on biodiversity conservation	1
	Energy dedicated crops may negatively impact biodiversity, especially if agroecological zoning is not respected.	
Socio-economic	Impact on energy availability	4
	The use of renewable resources such as solar power and biomass, and the possibility of using agricultural and forestry residues, represent an important step in the diversification of the energy matrix, positively contributing the energy availability.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and the need for skilled labor for the construction and installation of equipments, and for the operation of the power plant.	
	Competitive advantages of the country	5
	Brazil has a significant solar power potential. Furthermore, Brazil is a major producer and consumer of bioenergy. There are significant competitive advantages to the expansion of biomass use, especially when considering agricultural and forestry residues. Several ongoing CSP projects include the SMILE project, in Pirassununga (SP) and Caiçara do Rio do Vento (RN), and the project involving Petrobras, CTGAS-ER, USFC and UFRJ, in Vale do Açu (RN). In terms of R&D, COPPE/UFRJ, UnB, UNIFEI, Cepel/Eletrobras and UFRJ/Macaé have innovative lines of research in this field.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, synergies are verified due to the importance of bioenergy as an alternative to the ostensive use of fossil fuels, aiding in the reduction of GHG emissions, as well as other compounds that are harmful to human health.	
	Synergies with national climate policies	4
	The technology is not explicitly mentioned by national climate policies. However, national climate policies highlight the need for expanding the share of renewables and the incentives to solar power generation and bioenergy.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology is explicitly mentioned by the Country Programme Brazil for the Green Climate Fund (GCF). According to the programme, concentrated solar power is a promising technology in a structured arrangement for clean generation of both electricity and heat. In this context, the technology figures among new technologies that should be promoted and prioritized in the diversification of the Brazilian energy matrix.	
	Feasibility of adoption under the institutional framework	3
	The Programme of Incentive to Alternative Sources of Energy (Programa de Incentivo às Fontes Alternativas de Energia – PROINFA) has been instituted by law with the objective of enhancing the participation of energy generation from renewable resources, including bioenergy.	

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MACRO-CRITERIA	INDICATOR	SCORE
FLOATING SOLAR POWER PLANTS (ENERGY/ELECTRIC)		
Technological	Technology Readiness	5
	The technology is mature, with technology readiness level index 9. In Brazil, there is already a floating solar photovoltaic system installed at the Balbina hydroelectric plant in Presidente Figueiredo, Amazonas. It remains, however, to spread the technology to the full extent and scope of application in hydroelectric reservoirs (TRL 9).	
	Mitigation potential	1
	Considering a market penetration rate of 2.1% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 1,493 $ktCO_2eq$ per year (8),(9).	
	Mitigation cost	2
	Mitigation costs of 70-84 USD/tCO_2 (10).	
	Vulnerability to climate change	2
	Climate change may affect solar and water availability.	
Physical	Health and pollution reduction	4
	The technology can positively contribute to the reduction of pollution and health benefits by substituting fossil fuels in the power sector.	
	Impact on water availability	4
	The floating solar photovoltaic system aids in reducing the evaporation rate of the reservoir, which results in positive impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	2
	The installation of a floating solar photovoltaic system may negatively impact biodiversity, affecting the incidence of light in the reservoir, altering the environmental conditions, slowing the proliferation of algae and other microorganisms.	
Socio-economic	Impact on energy availability	5
	This technology can positively impact energy availability by using the already existing infrastructure and available space for additional energy generation.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and the need for skilled labor for the construction and installation of equipments (such as solar panels and the floating structure).	
	Competitive advantages of the country	5
	Brazil is a major producer of hydropower. The installation of floating solar photovoltaic systems benefits from an existing infrastructure and availability of space, while reducing evaporation rates of the hydropower reservoir. There is a floating solar photovoltaic system currently in operation in the country, in the Balbina hydroelectric power reservoir, located in Presidente Figueiredo, Amazonas. In terms of R&D, COPPE/UFRJ and Cepel/Eletrobras have innovative lines of research in this field.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	5
	The National Strategy for Science, Technology and Innovation highlights the growing participation of solar generation in energy matrixes worldwide and points out the advancements in national R&D in what regards photovoltaic cells, and solar panels.	
	Synergies with national climate policies	5
	National climate policies indicate the need to increase renewables participation in the Brazilian energy matrix (including solar generation).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The Country Programme Brazil for the Green Climate Fund (GCF) highlights the need to prioritize projects aiming at the diversification of the national energy matrix, including technologies such as solar photovoltaic for both distributed and centralized generation.	
	Feasibility of adoption under the institutional framework	5
	Several legal instruments in place can be applied to solar photovoltaic generation (centralized or distributed). For projects of centralized generation of over 5 MW, an authorization from the Ministry of Mines and Energy (MME) and the Brazilian Electricity Regulatory Agency (ANEEL) is required. Regulatory incentives include discounts of 50% for projects with 30 to 300 MW power to be injected into the grid, as well as exclusive federal auctions. Tax incentives include especial regimes to promote infrastructure development, such as "Regime Especial de Incentivos para o Desenvolvimento da Infraestrutura (REIDI)", as well as "Programa de Apoio ao Desenvolvimento Tecnológico da Indústria de Semicondutores e Displays (PADIS)". The first suspends taxation (PIS/COFINS) on services, sales or importation of machinery, equipments and materials, and the latter aims at attracting investments for the production of cells, modules, photovoltaic panels e strategic inputs for the productive chain.	

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MACRO-CRITERIA	INDICATOR	SCORE
CO_2 CAPTURE IN NATURAL GAS THERMOELECTRIC PLANTS (ENERGY/ELECTRIC)		
Technological	Technology Readiness	4
	The technology has been tested and qualified, with technology readiness level index 8 (4).	
	Mitigation potential	1
	Considering a market penetration rate of 1.2% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 853 kt CO_2eq per year (8),(9).	
	Mitigation cost	2
	Mitigation costs of 70-84 USD/tCO_2 (18).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	1
	CO_2 capture systems are highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	1
	CO_2 capture systems are highly energy intensive. For the specific case of CO_2 capture in natural-gas-fired thermoelectric power plants through post-combustion processes using amines, the solvent regeneration step imposes significant energy penalties to the whole generation system, which ends up increasing the costs of energy.	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and the need for skilled labor for the construction and installation of equipments, and for the operation of the power plant.	
	Competitive advantages of the country	3
	There is ongoing research in chemical absorption post-combustion carbon capture at COPPE/UFRJ and EQ/UFRJ. However, the technology is considered neutral on this criterion.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, the document highlights the need to develop knowledge regarding technological solutions in fields such as carbon capture and storage.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by the national climate policies. However, the Brazilian National Plan on Climate Change highlights the need to develop knowledge regarding technological solutions in fields such as carbon capture and storage.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	1
	Up to this moment, there is no information regarding legal instruments to promote this technology, especially in what regards the transportation and storage of the CO_2 captured.	

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MACRO-CRITERIA	INDICATOR	SCORE
CO_2 CAPTURE IN COAL-FIRED THERMOELECTRIC PLANTS (ENERGY/ELECTRIC)		
Technological	Technology Readiness	4
	The technology has been tested and qualified, with technology readiness level index 8 (4).	
	Mitigation potential	2
	Considering a market penetration rate of 1.2% in relation to base year (2015) and the emissions related to the power sector for the base year (electricity generation of 571,486 GWh and emission factor of the grid 0.1244 tCO_2/MWh), the mitigation potential is estimated at 853 kt CO_2eq per year (8,9).	
	Mitigation cost	2
	Mitigation costs of 70 USD/tCO_2 (18).	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	3
	Even if this technology reduces GHG emissions at a global scale, it does not directly affect the pollution and consequent health problems at a local scale.	
	Impact on water availability	1
	CO_2 capture systems are highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	1
	CO_2 capture systems are highly energy intensive. In the case of coal-fired thermoelectric power plants, CO_2 can be captured through post-combustion, pre-combustion and oxy-combustion processes. In both pre and post-combustion processes, the solvent regeneration step imposes significant energy penalties to the system. In oxy-combustion processes, there are additional energy penalties derived from the air separation unit (for oxygen supply).	
	Jobs and income generation	4
	The deployment of this technological route results in positive impacts on employment, income and the reduction of social inequality through the generation of new jobs and the need for skilled labor for the construction and installation of equipments, and for the operation of the power plant.	
	Competitive advantages of the country	4
	In terms of R&D, the Brazilian Association of Coal Mining (ABCM), COPPE/UFRJ, and EQ/UFRJ all have innovative lines of research in this field. Furthermore, CTCL/SATC is currently developing a pioneer pilot plant for post-combustion CO_2 capture via chemical adsorption.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not explicitly mentioned by the National Strategy for Science, Technology and Innovation. However, the document highlights the importance of coal as an energy resource for the country. In this context, there is a great challenge for the development of clean technologies for the production and use of coal in the national energy system.	
	Synergies with national climate policies	3
	The technology is not explicitly mentioned by the national climate policies. However, the Brazilian National Plan on Climate Change highlights the need to develop knowledge regarding technological solutions in fields such as carbon capture and storage.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not mentioned by the Country Programme Brazil for the Green Climate Fund.	
	Feasibility of adoption under the institutional framework	1
	Up to this moment, there is no information regarding legal instruments to promote this technology, especially in what regards the transportation and storage of the CO_2 captured.	

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MACRO-CRITERIA	INDICATOR	SCORE
SECOND GENERATION ETHANOL (ENERGY/BIOFUELS)		
Technological	Technology Readiness	3
	The technology is under demonstration stages, with technology readiness level index 6-7 (19).	
	Mitigation potential	1
	In order to estimate the mitigation potential of this technology, we assumed all excess bagasse to be directed to second generation ethanol production. For the base year 2015, total bagasse electricity generation reached 46 TWh. Considering: (i) a 35% efficiency, (ii) a 10% excess bagasse, (iii) a medium ratio of 55% of sugarcane directed to ethanol production in annex distilleries, (iv) a yield of 73 liters of ethanol per tonne of sugarcane, (v) a ratio of 0.244 tonnes of bagasse per tonne of sugarcane, and (vi) an emission factor of ethanol burning of 2.239 kg CO_2/l, we estimated a mitigation potential of 1,956 kt CO_2eq per year (8,9).	
	Mitigation cost	2
	Mitigation costs estimated between 25 and 100 USD/tCO_2.	
	Vulnerability to climate change	2
	Climate change may affect biomass and water availability, directly influencing land use.	
Physical	Health and pollution reduction	3
	The technology is considered neutral on this criterion.	
	Impact on water availability	1
	The production of advanced biofuels is highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	4
	The use of excess bagasse to the production of second-generation ethanol has positive impacts over energy availability by increasing ethanol supply in the biofuels national market.	
	Jobs and income generation	5
	The Brazilian sugar-energy sector positively impacts employment and income, reducing social inequality, especially in rural areas.	
	Competitive advantages of the country	5
	Brazil is a major producer of sugarcane and ethanol. The Brazilian sugar-energy sector is responsible for the production of sugar, ethanol and bioelectricity, figuring as one of the most well-established and developed sectors in the national frame. In terms of R&D, COPPE/UFRJ, EQ/UFRJ, INT, ITA, CTBE, UNICAM and USP, all have innovative lines of research in advanced biofuels, especially second-generation ethanol.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	5
	The National Strategy for Science, Technology and Innovation highlights the investments made through the Joint Plan BNDES-Finep for supporting technological and industrial innovation in the sugar-energy sector, as well as the research conducted by CTBE for the production of lignocellulosic ethanol, developing enzymes, microorganisms, and bioproducts. Additionally, the strategies point out the need for supporting research regarding biofuels, especially ethanol.	
	Synergies with national climate policies	5
	The Brazilian Nationally Determined Contribution (NDC) includes in its scope the increase of sustainable bioenergy share in the national energy matrix, which encompasses an increase in ethanol supply and advanced biofuels supply. The Renovabio Program highlights in its directives the need to guarantee competitiveness for biofuels in the Brazilian energy matrix, as well as the need to enforce mechanisms to promote ethanol competitiveness.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The Country Programme Brazil for the Green Climate Fund (GCF) mentions that investments in technologies for the production of advanced biofuels (focusing on second and beyond generations) should be a priority.	
	Feasibility of adoption under the institutional framework	5
	Ethanol is product certified and specified by the National Petroleum Agency (ANP).	

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MACRO-CRITERIA	INDICATOR	SCORE
GREEN DIESEL (ENERGY/BIOFUELS)		
Technological	Technology Readiness	3
	The main technological routes considered for the production of diesel biofuel were pyrolysis (technology readiness level index 4-6), hydrothermal liquefaction (technology readiness level index 4-5), and gasification followed by Fischer-Tropsch synthesis (technology readiness level index 6-7) (20). Two of the main technological routes are already in demonstration phases.	
	Mitigation potential	5
	For the estimation of the mitigation potential, we assume that diesel biofuel would replace conventional diesel fuel. For the base year 2015, conventional diesel fuel consumption was approximately 35 billion liters, according to the National Energy Balance (BEN-EPE) (8). Considering an emission factor of 2.632 kg CO_2/l, we estimate a mitigation potential of 92,120 kt CO_2eq per year (9).	
	Mitigation cost	2
	Mitigation costs are estimated between 25 and 100 USD/tCO_2.	
	Vulnerability to climate change	2
	Climate change may affect biomass and water availability, directly influencing land use.	
Physical	Health and pollution reduction	4
	Advanced biofuels have low Sulphur content, as well as other contaminants, which results in positive impacts for the reduction of pollution and health benefits.	
	Impact on water availability	1
	The production of advanced biofuels is highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	1
	The use of biomass for the production of advanced biofuels may negatively impact food production by the shifting the use of biomass from food production to energy generation. Additionally, land use and land use change aspects might also affect food production.	
	Impact on biodiversity conservation	1
	Energy dedicated crops may negatively impact biodiversity, especially if agro ecological zoning is not respected.	
Socio-economic	Impact on energy availability	4
	The use of renewable resources such as biomass and the possibility of using agricultural and forestry residues represent an important step in the diversification of the energy matrix, positively contributing the energy availability.	
	Jobs and income generation	5
	The development of advanced biofuels value chains has positive impacts on employment and income, reducing social inequality by creating jobs throughout the value chains, requiring skilled labor and delivering high added value products.	
	Competitive advantages of the country	5
	Brazil is a major producer of bioenergy and has significant competitive advantages for the expansion of biomass use, especially considering agricultural and forestry residues. In terms of R&D, COPPE/UFRJ, EQ/UFRJ, UNICAM and Cenpes/Petrobras, all have innovative lines of research in advanced biofuels, including diesel biofuel.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	The National Strategy for Science, Technology and Innovation highlights the need to support innovative lines of research and strategies for the development of advanced biofuels, in order to increase their competitiveness, in the light of their economic, social and environmental relevance.	
	Synergies with national climate policies	5
	The Brazilian Nationally Determined Contribution (NDC) includes in its scope the increase of sustainable bioenergy share in the national energy matrix, which encompasses an increase in ethanol supply and advanced biofuels supply. The Renovabio Program highlights in its directives the need to guarantee competitiveness for biofuels in the Brazilian energy matrix.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The Country Programme Brazil for the Green Climate Fund (GCF) mentions that investments in technologies for the production of advanced biofuels (focusing on second and beyond generations) should be a priority.	
	Feasibility of adoption under the institutional framework	4
	The various technological routes for the production of diesel biofuel are not yet fully specified. Nonetheless, in terms of chemical specifications, diesel biofuel is identical to conventional diesel fuel (with even higher quality: less Sulphur, and other contaminants). Therefore, the institutional framework for its deployment is considered favorable.	

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MACRO-CRITERIA	INDICATOR	SCORE
	BIOJET (ENERGY/BIOFUELS)	
Technological	Technology Readiness	2
	The main technological routes considered for the production of biojet fuels were pyrolysis (technology readiness level index 4-6), hydrothermal liquefaction (technology readiness level index 4-5), gasification followed by Fischer-Tropsch synthesis (technology readiness level index 6-7) (20), and the conversion of alcohol to jet (ATJ, technology readiness level index 5) (22). Three of the main technological routes are already in demonstration phases.	
	Mitigation potential	3
	For the estimation of the mitigation potential, we assume that biojet fuels would replace conventional aviation kerosene. For the base year 2015, conventional aviation kerosene consumption was approximately 4.4 billion liters, according to the National Energy Balance (BEN-EPE) (8). Considering an emission factor of 2.488 kg CO_2/l, we estimate a mitigation potential of 10,925 kt CO_2eq per year (21).	
	Mitigation cost	2
	Mitigation costs are estimated between 25 and 100 USD/tCO_2.	
	Vulnerability to climate change	2
	Climate change may affect biomass and water availability, directly influencing land use.	
Physical	Health and pollution reduction	4
	Advanced biofuels have low Sulphur content, as well as other contaminants, which results in positive impacts for the reduction of pollution and health benefits.	
	Impact on water availability	1
	The production of advanced biofuels is highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	1
	The use of biomass for the production of advanced biofuels may negatively impact food production by the shifting the use of biomass from food production to energy generation. Additionally, land use and land use change aspects might also affect food production.	
	Impact on biodiversity conservation	1
	Energy dedicated crops may negatively impact biodiversity, especially if agro ecological zoning is not respected.	
Socio-economic	Impact on energy availability	4
	The use of renewable resources such as biomass and the possibility of using agricultural and forestry residues represent an important step in the diversification of the energy matrix, positively contributing the energy availability.	
	Jobs and income generation	5
	The development of advanced biofuels value chains has positive impacts on employment and income, reducing social inequality by creating jobs throughout the value chains, requiring skilled labor and delivering high added value products.	
	Competitive advantages of the country	5
	Brazil is a major producer of bioenergy and has significant competitive advantages for the expansion of biomass use, especially considering agricultural and forestry residues. In terms of R&D, COPPE/UFRJ, UNICAM, ITA and Cenpes/Petrobras, all have innovative lines of research in advanced biofuels, including biojet fuels. Furthermore, a partnership between Embraer, Boeing, World Wide Fund for Nature (WWF), Roundtable on Sustainable Biomaterials (RSB) and the São Paulo Research Foundation (FAPESP) is investing in research for the identification of feedstocks as well as opportunities and challenges for the deployment of a sustainable cost-effective production and distribution chain of aviation biofuels in Brazil (23).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	5
	The National Strategy for Science, Technology and Innovation highlights the need to support innovative lines of research and strategies for the development of advanced biofuels, in order to increase their competitiveness, in the light of their economic, social and environmental relevance.	
	Synergies with national climate policies	5
	The Brazilian Nationally Determined Contribution (NDC) includes in its scope the increase of sustainable bioenergy share in the national energy matrix, which encompasses an increase in ethanol supply and advanced biofuels supply. The Renovabio Program highlights in its directives the need to guarantee competitiveness for biofuels in the Brazilian energy matrix, especially biojet fuels.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The Country Programme Brazil for the Green Climate Fund (GCF) mentions that investments in technologies for the production of advanced biofuels (focusing on second and beyond generations) should be a priority.	
	Feasibility of adoption under the institutional framework	4
	Advanced aviation biofuels are specified and certified by the International Air Transport Association (IATA).	

continues

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MACRO-CRITERIA	INDICATOR	SCORE
BIOBUNKER FOR MARITIME TRANSPORT (ENERGY/BIOFUELS)		
Technological	Technology Readiness	3
	The main technological routes considered for the production of biobunker fuels were pyrolysis (technology readiness level index 4-6), hydrothermal liquefaction (technology readiness level index 4-5), gasification followed by Fischer-Tropsch synthesis (technology readiness level index 6-7) (20), and gasification followed by biomethanol/DME synthesis (technology readiness level index 4-5) (20). Two of the main technological routes are already in demonstration phases.	
	Mitigation potential	1
	For the estimation of the mitigation potential, we assume that marine biobunkers would replace conventional bunker fuels. For the base year 2015, conventional diesel fuel and oil fuel consumptions were approximately 283 thousand m^3 and 757 thousand m^3, respectively, according to the National Energy Balance (BEN-EPE) (8). Considering the emission factors of 2,632 kg CO_2/m^3 (diesel fuel) and 3,108 kg CO_2/m^3 (oil fuel), we estimate a mitigation potential of 3,097 kt CO_2eq per year (21).	
	Mitigation cost	2
	Mitigation costs are estimated between 25 and 100 USD/tCO_2.	
	Vulnerability to climate change	2
	Climate change may affect biomass and water availability, directly influencing land use.	
Physical	Health and pollution reduction	4
	Advanced biofuels have low Sulphur content, as well as other contaminants, which results in positive impacts for the reduction of pollution and health benefits.	
	Impact on water availability	1
	The production of advanced biofuels is highly water demanding, resulting in significant negative impacts on water availability.	
	Impact on food production	1
	The use of biomass for the production of advanced biofuels may negatively impact food production by the shifting the use of biomass from food production to energy generation. Additionally, land use and land use change aspects might also affect food production.	
	Impact on biodiversity conservation	1
	Energy dedicated crops may negatively impact biodiversity, especially if agro ecological zoning is not respected.	
Socio-economic	Impact on energy availability	4
	The use of renewable resources such as biomass and the possibility of using agricultural and forestry residues represent an important step in the diversification of the energy matrix, positively contributing the energy availability.	
	Jobs and income generation	5
	The development of advanced biofuels value chains has positive impacts on employment and income, reducing social inequality by creating jobs throughout the value chains, requiring skilled labor and delivering high added value products.	
	Competitive advantages of the country	5
	Brazil is a major producer of bioenergy and has significant competitive advantages for the expansion of biomass use, especially considering agricultural and forestry residues. In terms of R&D, COPPE/UFRJ, EQ/UFRJ and Cenpes/Petrobras, all have innovative lines of research in advanced biofuels, including marine biofuels.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	The National Strategy for Science, Technology and Innovation highlights the need to support innovative lines of research and strategies for the development of advanced biofuels, in order to increase their competitiveness, in the light of their economic, social and environmental relevance.	
	Synergies with national climate policies	5
	The Brazilian Nationally Determined Contribution (NDC) includes in its scope the increase of sustainable bioenergy share in the national energy matrix, which encompasses an increase in ethanol supply and advanced biofuels supply. The Renovabio Program highlights in its directives the need to guarantee competitiveness for biofuels in the Brazilian energy matrix.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The Country Programme Brazil for the Green Climate Fund (GCF) mentions that investments in technologies for the production of advanced biofuels (focusing on second and beyond generations) should be a priority.	
	Feasibility of adoption under the institutional framework	2
	Advanced marine biofuels are not yet specified or certified by national or international agencies.	

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MACRO-CRITERIA	INDICATOR	SCORE
	VEHICLE SHARING (TRANSPORT/ROAD)	
Technological	Technology Readiness	3
	Autonomous vehicles (automated and connected) are in the testing phase, still below the operational scale (1). So, the TRL is between 6 and 7.	
	Mitigation potential	5
	It is estimated that the main effect of sharing would be the increase in the occupancy factor for light vehicles from 1.5 to 2.5 passengers per vehicle, which can be interpreted as a virtual reduction in the number of vehicles in the fleet, which corresponded to 32 million in 2015 (2). Thus, based on the annual gasoline consumption of 2015 of 30.2 billion liters (3) and considering the specific consumption of 10 km/l in light-duty vehicles powered by gasoline, the service in terms of passenger-kilometer (pkm) of the non-shared fleet is calculated. Assuming that this pkm (useful service) remains constant, it is then estimated that the vehicle fleet would fall to 19.2 million shared vehicles. Presuming, conservatively, that all these vehicles would continue to be supplied only with gasoline, a mitigation potential equivalent to 27,000 Gg CO_2 is estimated, only from the increase in vehicle occupancy.	
	Mitigation cost	1
	Vehicle sharing itself does not translate into high costs, hence most of the costs arise from the development of autonomous and connected vehicle technology. According to the discussion and estimates of (4), the Total Cost of Ownership (TCO) for autonomous vehicles would be, on average, about 0.80 USD/mile, the equivalent of 0.50 USD/km. For Internal Combustion Engine (ICE) Gasoline Vehicles, the TCO is stipulated at 0.355 USD/km (5). Based on these values and the calculated mileage for the fleet of gasoline-powered vehicles in 2015 (302 billion km), an annual total cost of USD 151 billion is estimated for Autonomous Vehicles, 43.8 billion USD more than for ICE gasoline. Thus, by dividing the difference between total costs by the mitigation potential of 27,000 Gg CO_2, the abatement cost for shared Autonomous Vehicles would be USD 1,619/tCO_2. This value reflects the TRL of the technology, which is not yet fully developed.	
	Vulnerability to climate change	3
	The technology is considered neutral on this criterion.	
Physical	Health and pollution reduction	5
	The reduction of the light-duty vehicles fleet circulating in the urban environment brings significant reductions in emissions, resulting in the reduction of urban pollution and benefits to the population's health.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	3
	The technology is considered neutral on this criterion.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral on this criterion.	
	Jobs and income generation	3
	Sharing rides through apps at first generates an increase in the number of jobs for app drivers, which has a positive impact on income generation. However, the insertion of autonomous vehicles goes against this trend, reducing the need for drivers for shared vehicles. Thus, it is considered that the effects of the technology on job and income generation are neutral.	
	Competitive advantages of the country	4
	Research centers and projects in Brazil include the Sustainable Mobility Center (Mob-i), integrated with Itaipu Binacional's Intelligent Mobility Program, which develops actions and projects related to sustainable mobility, supporting the management and operation of pilot projects for monitoring and sharing of electric vehicles, such as: Eco-Elétrico Curitiba, Ecomóvel Brasília, Mob-i UN and Mob-i Itaipu (6,7).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	5
	The document emphasizes the importance of connectivity and the Internet of Things, citing, among its applications, efficient control of automotive traffic and "connected cars that can act actively in accident prevention and even drive autonomously" (8).	
	Synergies with national climate policies	4
	The PNMC mentions the use of information and communication technology in transportation services (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document cites the improvement in passenger load factor, that is, the occupancy factor of vehicles, as an important element to increase efficiency in use and reduce emissions of urban transport in Brazil (10).	
	Feasibility of adoption under the institutional framework	1
	There is no regulatory framework for autonomous vehicles and there are barriers related to both the difficulty of regulating the dynamic functioning of an autonomous vehicle and the lack of public acceptance and ethical issues involving road traffic liability (11).	

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MACRO-CRITERIA	INDICATOR	SCORE
NATURAL GAS FOR WATER TRANSPORTATION (TRANSPORT/WATERWAYS)		
Technological	Technology readiness	5
	The design of liquefied natural gas (LNG) ships, the embedded systems and the technologies required for the use of LNG as a marine fuel can be considered proven and mature technologies (12). Technological challenges, in this case, involve both improvements in the motorization and tanking of natural gas in vessels according to their use and type, and the development of the liquefied natural gas supply system to vessels.	
	Mitigation Potential	1
	The use of LNG as a substitute for fuel oil in cabotage can reduce CO_2 emissions by about 20% (12). However, total emissions of cabotage activity in Brazil in 2015 are lower than the minimum mitigation to achieve a score greater than 1.	
	Mitigation cost	4
	It was not possible to quantitatively estimate the costs for the technology, so the discussion takes place qualitatively. The costs of implementing the technology refer to the adaptation of vessels to the use of LNG and the supply infrastructure. Compared to fuel oil vessels, investment costs are much higher, and there is also a reduction in carrying capacity, but operating costs are much lower (12). Despite these trade-offs, given the availability of GN in Brazil and how the technology is already developed, costs are considered relatively low.	
	Vulnerability to climate change	2
	Cabotage transport is somewhat vulnerable to climate change because of the expected more frequent occurrence of extreme natural events.	
Physical	Health and pollution reduction	4
	The use of GN as a substitute for fuel oil significantly reduces emissions of health-harmful compounds such as SOx, NOx and Particulate Matter (12). However, because the activity occurs in the maritime environment and not in the urban environment, health benefits to the population are relatively lower.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	2
	There may be competition for the use of GN with other sectors.	
	Jobs and income generation	4
	As oil production has been declining, the production of NG drives the current offshore Oil and Gas industry, which is significant in Brazil. Thus, there is the possibility of maintaining and/or generating jobs and income in the industry.	
	Competitive advantages of the country	4
	National advantages comprise the good availability of NG, which can make its use as a marine fuel economically interesting (12) and the great potential for cabotage transport (13), especially because of the shift from road to waterway transport. However, currently, the activity is still restricted.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	3
	The document expresses support for the natural gas offshore production.	
	Synergies with national climate policies	4
	PNMC highlights the expansion of the waterway system (interior navigation, cabotage and long haul) for cargo transport (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document considers both the shift from road to water transport for cargo and the use of less polluting fuels (10).	
	Feasibility of adoption under the institutional framework	2
	Cabotage in Brazil faces several difficulties, being: port inefficiency and high incident tariffs in the sector (such as loading, unloading and storing goods); the long waiting time for ship mooring, with some ports giving preference to the mooring of long-haul ships; high bureaucracy in port operations; the complex tax regime; the small number of regular routes, with low frequency of existing routes; inadequacies in port infrastructure and in infrastructure that enables intermodal integration (13,14).	

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MACRO-CRITERIA	INDICATOR	SCORE
USE OF NEW, LIGHTER MATERIALS IN VEHICLES (TRANSPORT/ROAD)		
Technological	Technology readiness	3
	The main needs are related to a better knowledge of the properties of the materials themselves and the processes related to their production and to the production of alloys. Thus, despite being already employed in the industry, their applications for the transport sector are still in the phase of development, improvement and testing (15,16). The TRL is 6.	
	Mitigation Potential	1
	The estimated consumption of diesel in 2015 by road freight transport was about 35 billion liters (3,17). Considering a diesel emission factor of 2,632 kg CO_2/l (18), emissions were estimated to be 92,123.2 Gg CO_2 for road transport of heavy-duty vehicles. It is estimated that the reduction of emissions by the use of lighter materials is about 4% in heavy-duty vehicles (19). Thus, the mitigation potential would be 3,685 Gg CO_2.	
	Mitigation cost	5
	A study of (19) showed that replacement costs for new lighter materials per heavy-duty vehicle can range from 300 to 5000 euros, with a payback time of 1 to 8 years. However, more advanced materials can make implementation more expensive. The report from (20) shows that the Total Cost of Owernship (TCO) of Internal Combustion Engine (ICE) diesel trucks is USD 0.8/km, with 0.4 USD/km corresponding to fuel expenditures. Thus, a 4% reduction in fuel consumption would take the TCO of ICE diesel trucks with lighter materials to USD 0.784/km. For a fleet of 1.5 million trucks and 189 billion km driven per year (35 billion liters of diesel and specific consumption of 5.4 km/l (17)), there would be an annual saving of USD 3 billion. For each truck, there would be an annual saving of USD 2,000. Thus, if the annual cost of deploying lighter materials is less than or equal to these savings, the cost of abatement is negative. Considering an investment of USD 5000 (just under 5000 euros) and a 10-year service life for the truck, the approximate annualized cost would be USD 500, which is less than the annual fuel economy achieved, resulting in a negative cost of abatement.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	4
	Reduction in the weight of vehicles requires lower fuel use, reducing emissions of urban transport.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Technology reduces fuel consumption, hence reducing energy demand.	
	Jobs and income generation	3
	The technology was considered neutral in this indicator.	
	Competitive advantages of the country	3
	The technology was considered neutral in this indicator.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	PNMC supports energy efficiency measures (21).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The document only considers measures to increase the energy efficiency of vehicle engines (10).	
	Feasibility of adoption under the institutional framework	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
	ELECTRIC TURBO-COMPOUND ENGINES (TRANSPORT/ROAD)	
Technological	Technology readiness	4
	The technology already exists and the TIGERS turbo-compound is sold (22), but is not widely applied and widespread in the market. Thus, its TRL is considered to be 8.	
	Mitigation Potential	1
	The estimated consumption of diesel in 2015 by road freight transport was about 35 billion liters (3,17). Considering a diesel emission factor of 2,632 kg CO_2/l (18), emissions were estimated as 92,123.2 Gg CO_2 for road transport of heavy-duty vehicles. It is assumed that the reduction of emissions by the use of electric turbo-compounds is about 2% in heavy-duty vehicles (19), which translates into a mitigation potential of 1,842.5 Gg CO2.	
	Mitigation cost	5
	A study of (19) showed that heavy-duty vehicle costs would be about 7000 euros, with a payback time that could reach more than 80 years. The report (20) shows that the Total Cost of Owernship (TCO) of Internal Combustion Engine (ICE) diesel trucks is 0.8 USD /km, with 0.4 USD/km corresponding to fuel expenditures. Thus, a 2% reduction in these expenses would take the TCO of ICE diesel trucks with electric turbo-compounds to 0.792 USD/km. For a fleet of 1.5 million trucks and 189 billion km driven per year (35 billion liters of diesel and specific consumption of 5.4 km/l (17)), it would generate annual savings of USD 1.5 billion. For each truck, there would be an annual saving of USD 1,000. Thus, if the annual cost of installing an electric turbo-compound is less than or equal to these savings, the cost of abatement is negative. Considering an investment of USD 7000 (just under 7000 euros) and 10-year service life for the truck, the approximate annualized cost would be USD 700, which is less than the annual fuel savings achieved, resulting in a negative cost of abatement.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	4
	Reduces fuel use thereby reducing emissions from urban transportation.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Technology reduces fuel consumption, hence reducing energy demand.	
	Jobs and income generation	3
	Although Tenneco Powertrain's Federal Mogul, which produces the TIGERS, is based in the country (22), production is not considered to have a scale to generate more jobs or income. Thus, the technology was considered neutral in this indicator.	
	Competitive advantages of the country	3
	Although Tenneco Powertrain's Federal Mogul, which produces the TIGERS, is based in the country (22), Brazil is not considered to have an advantage over other countries. Thus, the technology was considered neutral in this indicator.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	PNMC supports energy efficiency measures (21).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The document only considers measures to increase the energy efficiency of vehicle engines (10).	
	Feasibility of adoption under the institutional framework	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
	SMART CONVOY SYSTEM (TRANSPORT/ROAD)	
Technological	Technology readiness	3
	There have been tests with drivers on board and the technology already works. The ENSEMBLE project aims to test the real system on the streets in 2021 (23,24). So, the TRL is 6.	
	Mitigation Potential	2
	The reduction in fuel consumption reaches 10% considering the average between the leading truck and the others, which have reductions greater than the leader (2,25). The estimated consumption of diesel in 2015 by road freight transport was about 35 billion liters (3,17). Considering a diesel emission factor of 2,632 kgCO2/l (18), emissions were estimated to be 92,123.2 Gg CO_2 for heavy-duty road transport. Thus, the mitigation potential would reach 9,212 Gg CO_2.	
	Mitigation cost	5
	No quantitative estimates were found for the implementation costs of Truck Platooning systems. However, technology costs are associated with changes in trucks and not major structural changes, which can still be offset by a 10% reduction in fuel spending. The report from (20) shows that the TCO of ICE diesel trucks is 0.8 USD/km, with 0.4 USD/km corresponding to fuel expenditures. Thus, a 10% reduction in these expenses would take the TCO of ICE diesel trucks with Truck Platooning systems to 0.76 USD/km. That is, for a fleet of 1.5 million trucks and 189 billion km driven per year (35 billion liters of diesel and specific consumption of 5.4 km/l (17)), it would generate annual savings of USD 7.5 billion. For each truck, there would be an annual saving of USD 5,000. Thus, if the annual cost of implementing the Truck Platooning System is less than or equal to these savings, the cost of abatement is negative. Considering 10 years of service life for the truck, in order for the cost of abatement to be positive, an initial investment of around USD 50,000 per truck would be required.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	4
	The reduction of about 10% in diesel consumption leads to the reduction of urban pollution.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Technology reduces fuel consumption, reducing energy demand.	
	Jobs and income generation	2
	The dissemination of the use of Truck Platooning for cargo transportation tends to dispense the presence of drivers in the trucks that follow the leading truck. Thus, in a country highly dependent on road transport for cargo, the number of truck drivers could suffer a substantial drop.	
	Competitive advantages of the country	4
	Large space for the application of the technology, since most cargo transport is made through road trucks.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC mentions the use of information and communication technology in transportation services (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The technology was considered neutral in this indicator.	
	Feasibility of adoption under the institutional framework	1
	Difficulty in creating a regulatory framework, with the definition of responsibilities and technical specifications.	

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MACRO-CRITERIA	INDICATOR	SCORE
FLEX HYBRID VEHICLES (TRANSPORT/ROAD)		
Technological	Technology readiness	5
	The first flex hybrid vehicle has been launched in Brazil by Toyota in 2019 and is already available in the market. So, TRL is 9.	
	Mitigation Potential	5
	Under the premises that a flex vehicle with an internal combustion engine (ICE) presents a fuel consumption of 10km/L and that the flex hybrid would present an average consumption in the city of 20km/L (26), that is, it would be 50% more efficient than the ICE, the consumption of automotive gasoline 2015 (3) would fall by half. Considering the emission factor of gasoline as 2,239 kg CO_2/L (18), the increase in efficiency results in a reduction in emissions of 33,813 Gg CO_2. If, instead of gasoline, ethanol is used as fuel for the hybrid flex engine, this reduction is even greater.	
	Mitigation cost	2
	Despite the high cost of acquiring hybrid cars, with Toyota Corolla Altis Hybrid costing around R$ 140,000, about 3 times the price of a popular car, there will be significant fuel savings over its lifetime. Additional costs such as insurance and repairs/maintenance should be more expensive than those of a conventional car, as it is a new technology on the market. According to the report of (5), the Total Cost of Ownership (TCO) of gasoline vehicles is 0.355 USD/km. For hybrid vehicles, it would be 0.36 USD/km. It is assumed that in 2015 gasoline vehicles ran about 302 billion km (30.2 billion liters of gasoline consumed (3) with fuel consumption of 10 km/l). Thus, the total annual cost of the Hybrid Vehicle fleet would be USD 108.7 billion, 1.5 billion more than for ICE gasoline vehicles. Thus, by dividing this cost difference by the mitigation potential of 33,813 Gg CO2, an abatement cost of USD 44.7/tCO_2 is estimated.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	5
	Significant reductions in emissions from burning gasoline and in noise pollution in the urban environment.	
	Impact on water availability	4
	With the increase in the energy efficiency of the vehicle, the demand for ethanol decreases and, consequently, for water for irrigation of sugarcane plantations.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	Impact on energy availability	4
	Technology increases the energy efficiency of vehicles, reducing energy demand.	
	Jobs and income generation	4
	It is expected that the current car production chain will adapt to that of electric cars and that a new value chain linked to electric cars will also be created, if they are assembled in the country (27). With the production of Toyota's flex hybrid vehicle, for example, being held at the Indaiatuba plant, in São Paulo, many investments are attracted, and jobs are expected to be generated, including in the electric engine branch of the automotive industry. With regard to the country's fuel sector, it is estimated that jobs in the area of biofuels, such as ethanol, are maintained with the use of Flex Hybrids (Plug-in or not) and that in the area of oil the reduction effect is not immediate (27).	
	Competitive advantages of the country	5
	The first flex hybrid vehicle is being produced in Brazil by Toyota, in the Indaiatuba plant, São Paulo, in which about R$ 1 billion were invested (28). However, the hybrid set is still imported and companies only intend to produce them in the country with increased demand and national production of hybrid vehicles (29). Also in the field of the nationalization of technology, among the 694 patent applications for electric and hybrid vehicles in Brazil, only 21 are from residents in the country, 7 from universities, 1 from a governmental research center (CPQD), 6 companies and 7 of independent inventors; and with regard to technologies, 3 are related to hybrid vehicles, 8 to electric vehicles and 10 to batteries (30). However, an extremely favorable point is that, because of the broad national presence of vehicles with flex engines, the country has significant advantages in the production and distribution of ethanol as automotive fuel (31). Thus, flex hybrid vehicle technology puts the country in a position of wide advantage, with the use of national technology and resources.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	Among its objectives, the document aims to strengthen the national competitiveness of biofuels, especially ethanol (32).	
	Synergies with national climate policies	5
	The PNMC emphasizes the need to promote energy efficiency in vehicles and the use of biofuels (9). RenovaBio aims to promote and ensure the expansion of the use of biofuels, such as ethanol.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document promotes the energy efficiency of vehicle engines, electromobility and the use of biofuels (10).	
	Feasibility of adoption under the institutional framework	5
	The use of biofuels, such as ethanol, is widely encouraged in Brazil and Toyota's project is supported by the Sugarcane Industry Union (UNICA) (31). The Rota 2030 Program (33) promotes the use of biofuels, electromobility and, in particular, the use of Flex Hybrids, energy efficiency and technological innovation. The program grants tax incentives such as the exemption of IOF (Financial Operations Tax) and IPI (Tax on Industrialized Products) on electric and hybrid vehicles. These incentives help pass barriers to hybrid vehicles such as high acquisition costs, which in turn lead to cultural barriers on the part of consumers, which generally pay attention only to vehicle acquisition costs. In addition, subsidies and the strengthening of the biofuel chain such as ethanol can help break another cultural barrier, which is the preference for gasoline due to the lower cost and/or habit.	

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MACRO-CRITERIA	INDICATOR	SCORE
PARTIAL OR TOTAL ELECTRIFICATION OF TRAINS (TRANSPORT/RAIL)		
Technological	Technology readiness	5
	The technology of electric locomotives, both for passenger and cargo transport, is already available and widely used in several countries (34). However, innovative projects include the hybridization of existing diesel locomotives, with the use of batteries and fuel cells. Examples are: Rolls-Royce's MTU Hybrid PowerPacks and shift2rail project (35,36).	
	Mitigation Potential	1
	Total emissions calculated on the basis of diesel fuel consumption of the 2015 rail modal (3) are lower than the cutoff value corresponding to reach score 1.	
	Mitigation cost	1
	It was not possible to quantitatively estimate the costs for the technology, so the discussion takes place qualitatively. According to a study (37), the capital cost (CAPEX) of electric railways would be between 10 and 18% higher than for diesel railways, while the cost of operation (OPEX) would have an annual reduction of 55%. However, investment costs in the electrification of the Brazilian rail network include the hybridization of existing trains and/or the exchange of all existing structures by catenaries, whether for cargo or urban transport. Thus, it is configured as a high investment, in terms of scale, for a very low mitigation potential in the Brazilian context.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	5
	Hybrid locomotives may present reductions in the order of: 25% of diesel consumption, 75% of noise pollution, 70% of NOx emissions and 90% of particulate matter (38).	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	The energy generated for the operation of the railway and throughout its extension could improve access to energy for local populations, especially those isolated (37). In addition, technology is more efficient, reducing energy demand.	
	Jobs and income generation	5
	Increased employment and income by factors such as: generation of local socioeconomic development; professional qualification of the local workforce (operation, engineering, administration and management); development of suppliers in the industry sectors, local service providers and trade and, with this, the demand for more jobs (37).	
	Competitive advantages of the country	3
	The technology was considered neutral in this indicator.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC highlights the expansion of the rail system for freight transport (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document supports electromobility and advises the shift of freight transport from road to rail (10).	
	Feasibility of adoption under the institutional framework	2
	Transport policy is currently focused on road logistics. Actions are needed to encourage the modernization and expansion of rail transport as a whole, and more specifically, to its electrification (37).	

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<table>
<tr><th>MACRO-CRITERIA</th><th>INDICATOR</th><th>SCORE</th></tr>
<tr><th colspan="3">MAGNETIC LEVITATION (MAGLEV) SYSTEMS FOR TRAINS (TRANSPORT/RAIL)</th></tr>
<tr><td rowspan="8">Technological</td><td>Technology readiness</td><td>2</td></tr>
<tr><td colspan="2">There are few Maglev train projects in commercial operation in the world, with short-haul lines, around 30 km, and that are concentrated in Asia (39). However, there are several functional prototypes on a non-commercial scale and in development. Examples include MagLev-Cobra, which is under development in the Laboratory of Superconductor Applications - LASUP of COPPE/UFRJ, a prototype SML vehicle that aims to revolutionize urban transport (40); and Hyperloop, which is beginning its testing phase to go into commercial operation in Abu Dhabi (41). Thus, the TRL of the technology is considered to be between 4 and 5, receiving a score of 2.</td></tr>
<tr><td>Mitigation Potential</td><td>1</td></tr>
<tr><td colspan="2">Total emissions calculated on the basis of diesel fuel consumption of the 2015 rail modal (3) are lower than the cutoff value corresponding to reach score 1.</td></tr>
<tr><td>Mitigation cost</td><td>1</td></tr>
<tr><td colspan="2">It was not possible to quantitatively estimate the costs for technology, so the discussion takes place qualitatively.
The proposed MagLev costs to connect the cities of Baltimore and Washington in the U.S. are of around USD 400 million per mile, about USD 234 million per km (42). Thus, and also because the technology has a very low TRL, the costs are considered very high for a small mitigation potential in the Brazilian context.</td></tr>
<tr><td>Vulnerability to climate change</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td rowspan="8">Physical</td><td>Health and pollution reduction</td><td>5</td></tr>
<tr><td colspan="2">Reduction of NOx emissions and particulate matter and noise pollution, when compared to the use of diesel trains or cars for urban transport (43).</td></tr>
<tr><td>Impact on water availability</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td>Impact on food production</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td>Impact on biodiversity conservation</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td rowspan="6">Socio-economic</td><td>Impact on energy availability</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td>Jobs and income generation</td><td>4</td></tr>
<tr><td colspan="2">Creation of value chain and generation of jobs at all stages of projects (research, construction and operation). In the case of urban transport, generation of improvements in the quality and availability of passenger transport, and possible reduction of travel time for long distances, and there may be a positive effect on income generation for workers.</td></tr>
<tr><td>Competitive advantages of the country</td><td>4</td></tr>
<tr><td colspan="2">Brazil's greatest competitive advantage is that technology is already being developed and tested in the country, with MagLev-Cobra, a prototype of the Laboratory of Superconductor Applications - LASUP of COPPE/UFRJ (40).
In addition, HyperloopTT has its headquarters in the country and has inaugurated a logistics innovation center in the city of Contagem, in the state of Minas Gerais, and also announced the Hyperloop Academy initiative in Brazil, an education project that aims to connect educational institutions and innovation programs around the world to the company's 900 scientists and partners. Institutions such as the School of Engineering of Minas Gerais and UFMG have already expressed interest in partnering with the academy (44).</td></tr>
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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC highlights the expansion of the rail system for freight transport (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document attests that investment in transport modals should consider lower GHG emission systems and greater efficiency, with priority for urban passenger, subway and urban train transport infrastructure proposals (10).	
	Feasibility of adoption under the institutional framework	2
	Transport policy is currently focused on road logistics. Because it is a technology with high investment costs and the need for research and development, it can be hampered by the lack of tax incentives.	

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MACRO-CRITERIA	INDICATOR	SCORE
PARTIAL OR TOTAL ELECTRIFICATION OF VESSELS USING RENEWABLE ENERGY (TRANSPORT/WATERWAYS)		
Technological	Technology readiness	5
	The electric propulsion of boats has been employed for over 100 years. The current challenge concerns battery technology (price, size, autonomy) and recharging infrastructure that enables large-scale electrification and long-distance transportation. In any case, there are already boats operating or in the development phase for applications ranging from cargo transport to short-distance passenger ferries (45,46).	
	Mitigation Potential	1
	The total emissions calculated based on the consumption of diesel oil and fuel oil of the 2015 waterway modal (3) are lower than the cutoff value corresponding to score 1.	
	Mitigation cost	4
	It was not possible to quantitatively estimate the costs for technology, so the discussion takes place qualitatively. Hybridization or total electrification of vessels require high investment costs (CAPEX), as was the case with the project of the Swedish company ForSea Ferries (formerly HH Ferries) which launched 2 fully electric ferries and cost around 29 million euros, of which 11.5 were subsidized by the European Union (47,48). However, there are also reductions in operating costs (OPEX), due to both fuel savings and reduced maintenance of electric motors, being considered economically viable (45,49). Thus, because it is a technology with high TRL, with good insertion potential, especially in short-distance routes, and with structural needs that involve only electrical recharging, it is understood that its costs are relatively low.	
	Vulnerability to climate change	2
	Considering vessels that depend on solar or wind energy generation for electric propulsion, these technologies are considered vulnerable to changes in the availability of these natural resources.	
Physical	Health and pollution reduction	4
	Electrification does not produce direct emissions and hybridization generates significant reductions in NOx emissions and particulate matter because of fuel savings (49). However, for most emissions that do not occur in the urban environment, score 4 was given.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	4
	Electric motors generate less noise pollution, which, in this case, is perceived mainly by marine fauna. Thus, electrification can bring a reduction in the negative impact on biodiversity.	
Socio-economic	Impact on energy availability	4
	Technology increases the energy efficiency of the activity, reducing energy demand.	
	Jobs and income generation	3
	Whereas the greatest potential for the insertion of electric vessels is in the short distance transportation, whether in passenger or recreational transport, there will be no great need for civil construction or electrical and port infrastructure to meet the activity requirements. As for the construction/adaptation of vessels and components, it is considered to be carried out by the existing industry or otherwise imported.	
	Competitive advantages of the country	4
	LabH2 - COPPE/UFRJ's "Electric Propulsion Vessel Series Heads" project, in partnership with Furnas Centrais Elétricas S/A, aims to develop 2 prototypes of electric vessels: an Electric-Hybrid Ferry and a Triptych Speedboat, for the transport of vehicles and passengers in reservoirs of Hydroelectric Power Plants - Furnas HPP and in Rio de Janeiro (50). There are also several teams and universities involved in prototype projects of solar-powered boats that participate in the "Solar Brazil Challenge" competition (51). Another advantage lies in the fact that Brazil has a highly renewable electrical matrix, contributing to the possibility of electrification with low emissions.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC cites the use of efficient vehicles and the expansion of the use of waterway systems (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document cites electromobility for urban passenger transport, which may include hybrid/electric ferries and also supports renewable energy generation (10).	
	Feasibility of adoption under the institutional framework	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
	IMPROVEMENT OF AIRCRAFT AERODYNAMICS (TRANSPORT/AIR)	
Technological	Technology readiness	1
	The concepts are proven, but the technologies themselves are still being developed, many still without prototypes. Thus, TRL 3 is attributed to the set of technologies that improve aircraft aerodynamics, whether concerning design changes or the use of advanced materials.	
	Mitigation Potential	1
	A 20% reduction in fuel consumption was considered based on Blended Wing Body (BWB) technology (52,53). Thus, based on the values of aviation kerosene and aviation gasoline consumption in the air sector in 2015 (3) and the emission factors of the Third Brazilian Inventory of Anthropic Greenhouse Gas Emissions and Removals (18), a reduction of 2,213 Gg CO_2 in emissions was calculated.	
	Mitigation cost	1
	It was not possible to quantitatively estimate the costs for technology, so the discussion takes place qualitatively. Since the TRL of the technology set is very low, with a need for extensive research and development, it is estimated that the costs are relatively very high for a relatively low mitigation potential in the Brazilian context.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	4
	Given the reduction in fuel expenditure of about 20%, atmospheric emissions are reduced. However, as pollution is not local, that is, it does not occur effectively in the urban environment, technology has received score 4.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	3
	Technology reduces fuel usage thereby reducing energy demand.	
	Jobs and income generation	3
	The technology was considered neutral in this indicator.	
	Competitive advantages of the country	4
	Embraer developed a new winglet for the Ipanema 203 agricultural aircraft, achieving improvements in its aerodynamics (54). The VE Program, from Itaipu Binacional, through the electric plane project, in partnership with ACS Aviation, from São José dos Campos (SP), studies the composite materials used in aircraft, aiming at reducing the weight of electric vehicles. However, as it is being considered a set of possible technologies and no other Brazilian research initiatives were found in this context, the technology is considered neutral in this criterion.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC cites the use of efficient vehicles (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	3
	The technology was considered neutral in this indicator.	
	Feasibility of adoption under the institutional framework	2
	There are several barriers to the use of BWB aircraft, for example, for commercial air transport, among them: difficulties with logistics and movement at airports, minimum height requirements for the transport of passengers that conflict with the aircraft design, and the inflexibility of design (55). In addition, there are cultural barriers to changing the design of commercial aircraft. The use of new lighter materials and innovative product manufacturing techniques also requires the establishment of quality standards and norms by the aviation industry (56).	

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MACRO-CRITERIA	INDICATOR	SCORE
ELECTRIFICATION OF AIRCRAFT USING RENEWABLE ENERGY (TRANSPORT/AIR)		
Technological	Technology readiness	3
	There are about 100 electric aircraft programs under development in the world (57,58), including: Boeing's SUGAR Volt, which has a hybrid propulsion system, and which application in jets is expected to be launched between 2030 and 2050; Airbus's E-Fan X hybrid aircraft in partnership with Rolls-Royce and Siemens, which first flight tests are expected to be carried out in 2021; Sora-e, which made the first flight in Latin America in 2015, and is a two-seater twin-engine developed by ACS-Aviation, from São José dos Campos, in the interior of São Paulo, in partnership with Itaipu Binacional; the project between Embraer and WEG, which will develop a prototype of the single-engine agricultural EMB-203 Ipanema with 100% electric propulsion and flight autonomy of approximately 30 minutes and which laboratory tests are expected to take place until 2020. For solar electric aircrafts, in March 2016, Solar Impulse flew more than 40,000 kilometers around the world using only the energy of the sun (27). Thus, given the existence of functional prototypes that are in the testing phase in a simulated laboratory or operational environment, TRL 6 was assigned for the technology, receiving a score of 3.	
	Mitigation Potential	1
	According to engineer André Gasparotti, Director of Technological Development at Embraer (58), the shift from aviation kerosene to electrification may generate a gain of 40% to 50% in energy efficiency. Thus, assuming a 50% reduction in the energy consumption of the aviation sector in 2015 (3) and considering the emission factor of 0.4 kg CO_2/KWh, the potential for mitigation of electrification reached 2,558 Gg CO_2. The emission factor of 0.4 kg CO_2/kWh is equivalent to the generation of a natural gas thermoelectric plant, conservatively simulating the electrical generation dedicated to the supply of electric vehicles. However, the ideal for emissions mitigation is that generation is from renewable sources	
	Mitigation cost	1
	It was not possible to quantitatively estimate the costs for technology, so the discussion takes place qualitatively. Aircraft electrification demands high investment costs, which are significantly dependent on the acquisition and exchange/maintenance costs of batteries and on their energy density. On the other hand, it can bring savings, for example, because there is no need for an auxiliary system to generate electricity for other uses of the aircraft other than propulsion and the lower need for maintenance of electric motors in relation to mechanics. However, in the current market context, economic instruments that favor the cheapening of renewable electricity generation and carbon pricing are essential for the beginning of the development of electric aircraft (59). With this, and because it still presents a relatively low TRL, the cost of technology was considered relatively expensive for a relatively low mitigation potential in the Brazilian context.	
	Vulnerability to climate change	2
	About solar aircrafts with on-board electrical generation from solar energy, climate change affecting the availability of renewable resources or temperature changes in certain regions affecting generation efficiency are considered vulnerabilities.	

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MACRO-CRITERIA	INDICATOR	SCORE
Physical	**Health and pollution reduction**	4
	Reduction in NOx emissions during takeoff and landing in the airport area (59).	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	**Impact on energy availability**	4
	Technology increases the energy efficiency of the activity, reducing energy demand.	
	Jobs and income generation	3
	The technology was considered neutral in this indicator.	
	Competitive advantages of the country	4
	Among the research projects developed in the country are (58,60,61): Sora-e, which made the first flight in Latin America in 2015, and is a two-seater twin-engine developed by ACS-Aviation, from São José dos Campos, in the interior of São Paulo, in partnership with Itaipu Binacional; the project between Embraer and WEG, which will develop a prototype of the single-engine agricultural EMB-203 Ipanema with 100% electric propulsion. Embraer is also involved in a project with Uber for the deployment of small electric vertical take-off and landing vehicles for shorter urban displacements (62). Another advantage lies in the fact that Brazil has a highly renewable electrical matrix, contributing to the possibility of electrification with low emissions. Therefore, it would be one of the countries in the world with the greatest potential to reduce CO_2 emissions through the use of electricity in place of fuel in aircrafts (59).	
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC cites the use of efficient vehicles and a modest expansion of air transport (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The document supports the promotion of energy efficiency measures and low-carbon modes in the transport sector and also the generation of renewable energy (10).	
	Feasibility of adoption under the institutional framework	2
	Need for mechanisms that promote battery cheapening, renewable generation and carbon pricing for technology to become competitive (59). Lack of international certification for electric and hybrid aircrafts (63).	

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<table>
<tr><th>MACRO-CRITERIA</th><th>INDICATOR</th><th>SCORE</th></tr>
<tr><td colspan="3">PLUG-IN HYBRID ELECTRIC VEHICLES (TRANSPORT/CROSS-SECTORAL)</td></tr>
<tr><td rowspan="8">Technological</td><td>Technology readiness</td><td>5</td></tr>
<tr><td colspan="2">The technology already has a commercial scale. Plug-in Hybrid sales accounted for 1/3 of electric vehicle sales in 2017 and exceeded battery electric vehicles (BEV) sales in countries such as Japan, Sweden and the United Kingdom (64). The main technological challenges concern batteries, due to the need for cheapening and increasing autonomy (65).</td></tr>
<tr><td>Mitigation Potential</td><td>5</td></tr>
<tr><td colspan="2">Plug-in Hybrids, in view of the possibility of using the internal combustion engine (ICE) and raising the autonomy to more than 750 km, have smaller batteries, with less than 100 km autonomy range (65). Thus, fuel and electricity consumption depend on the typology of vehicle use, but generally, fuel savings are greater than 50% (66,67). Thus, estimates considered that: a Plug-in Hybrid runs 50% of the time with the electric motor and 50% with the efficient ICE; ICE fuel consumption of 18km/L and electric motor consumption of 19.3 kWh/100km (68); automotive gasoline consumption in 2015 (3); and emission factors of 2,239 kg CO_2/L for gasoline and of 0.4 kg CO_2/kWh for the electrical generation. Hence, the mitigation potential was calculated at 37,182 Gg CO_2. If instead of gasoline, ethanol is used as fuel in Flex Plug-in Hybrids, this potential is even greater. The emission factor of 0.4 kg CO_2/kWh is equivalent to the generation of a natural gas thermoelectric plant, conservatively simulating the electrical generation dedicated to the supply of electric vehicles. However, the ideal for emissions mitigation is that generation is from renewable sources.</td></tr>
<tr><td>Mitigation cost</td><td>1</td></tr>
<tr><td colspan="2">According to estimates from (68) for the U.S., the acquisition cost of Plug-in Hybrids is much higher than conventional vehicles, but lower than battery electric vehicles (BEVs). Much of this cost is due to the high cost of batteries. Thus, with the expected drop in battery prices, the costs of electric vehicles will fall, but plug-in hybrids will remain more expensive than conventional vehicles, BEVs may be even cheaper. In addition to the cost of batteries, there is another factor that interferes a lot in the cost difference, which is fuel savings. Considering the total costs of 5 years of vehicle operation, the difference between Plug-in hybrids and conventional hybrids decreases, but Plug-in Hybrids do not become cheaper than conventional ones on the horizon until 2030, while BEVs become around 2025. Thus, comparatively, Plug-in Hybrids may be favored in the short term by presenting prices closer to conventional vehicles and if there are incentive policies to buy them.
According to the report of (5), the Total Cost of Ownership (TCO) of Gasoline Vehicles is 0.355 USD/km. For Plug-in Hybrid Vehicles, it would average 0.375 USD/km. It is assumed that in 2015, Gasoline Vehicles drove around 302 billion km (30.2 billion liters of gasoline consumed (3) at a fuel consumption of 10 km/l). Thus, the total annual cost of Plug-in Hybrid Vehicles (for the entire fleet) would be USD 113.3 billion, 6 billion more than for gasoline ICE. Thus, by dividing this cost difference by mitigation potential of 37,182 Gg CO_2, an abatement cost of USD 162.5/tCO_2 is estimated.</td></tr>
<tr><td>Vulnerability to climate change</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td rowspan="8">Physical</td><td>Health and pollution reduction</td><td>5</td></tr>
<tr><td colspan="2">Significant reduction in emissions from burning gasoline and the reduction of noise pollution in the urban environment.</td></tr>
<tr><td>Impact on water availability</td><td>4</td></tr>
<tr><td colspan="2">With the increase in the energy efficiency of the vehicle, the demand for ethanol decreases and, consequently, for water for irrigation of sugarcane plantations.</td></tr>
<tr><td>Impact on food production</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
<tr><td>Impact on biodiversity conservation</td><td>3</td></tr>
<tr><td colspan="2">The technology was considered neutral in this indicator.</td></tr>
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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	**Impact on energy availability**	4
	Technology increases the energy efficiency of vehicles, reducing energy demand.	
	Jobs and income generation	5
	According to studies on electrification in Europe (69,70), there may be a reduction in jobs in the car manufacturing sector because the process of producing electric vehicles is simpler than that of vehicles with ICE. For Plug-in Hybrid vehicles, however, activity is more job intensive than for fully electric vehicles, as it combines both production chains, bringing a positive effect on job creation and making net jobs in the manufacturing sector dependent on the proportion of Plug-in Hybrids being produced (69,71). For electric vehicles in general, another effect concerns the creation of jobs in other areas, such as: installation, operation and maintenance of recharging stations, battery production, electrical generation and distribution projects and other indirect jobs (69). Thus, it is estimated that jobs must change and adapt, obtaining a positive final balance, if vehicles are produced in the country itself. Otherwise, losses to Europe, for example, would be significant (70). For Brazil, it is expected that the conventional car production chain adapts to that of electric cars and that there is the creation of a new value chain linked to electric cars, if they are assembled in the country. Concerning the national fuel sector, it is estimated that jobs in the area of biofuels, such as ethanol, are maintained with the use of Flex Hybrids (Plug-in or not) and that in the area of oil the reduction effect is not immediate (27).	
	Competitive advantages of the country	3
	The technology has not yet been nationalized and automotive companies only intend to produce hybrid systems in the country in the face of increased demand and national production of hybrid vehicles (29). Among the 694 patent applications for electric and hybrid vehicles in Brazil, only 21 are from residents in the country, 7 of which come from universities, 1 from a government research center (CPQD), 6 of companies and 7 from independent inventors; with regard to technologies, 3 are related to hybrid vehicles, 8 to electric vehicles and 10 to batteries (30). Moreover, there is still no public electrical recharge infrastructure that meets a wide demand for electric vehicles. On the other hand, there are several electromobility projects in the country, such as: Itaipu Binacional's VE and Mob-i Programs (7,60); the Cities Project, from Renault, which provides electric vehicles for projects in different cities (72): the Mob-i, in Foz do Iguaçu; Curitiba Ecoelétrico; The Brasilia Ecomobile; CPFL Energia's Electric Mobility Program in Campinas; a project for zero-emission transportation in Rio de Janeiro; and Celpe's Intelligent Electrical Networks Project in Fernando de Noronha. As for recharging infrastructure, companies have already invested in the installation of stations in Brazil (73), such as CPFL Energia in São Paulo, Copel in Paraná and EDP in partnership with BMW on the Presidente Dutra Highway, which connects SP to RJ. These projects, despite most encompassing purely electric cars, can leverage national technology, encourage demand and create minimal infrastructure for the development of the Plug-in Hybrid, which is seen by many as the first step towards sector electrification (73). Another advantage lies in the fact that Brazil has a highly renewable electrical matrix, contributing to the possibility of electrification with low emissions.	
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	5
	The PNMC emphasizes the need to promote energy efficiency in vehicles and the use of biofuels (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document promotes the energy efficiency of vehicle engines, electromobility and the use of biofuels (10).	
	Feasibility of adoption under the institutional framework	4
	The Brazilian EVs market has been only following from a distance what happens in the international market. The differences in incentive to electromobility are precisely because the main motivation of other countries is to have electrification as the best solution for the decarbonization of the energy matrix, while in Brazil there are other options, such as the use of biofuels (73). However, the market has been growing, prices have been falling and the government has been giving good signs. The Rota 2030 Program (33) promotes the use of biofuels, electromobility and, in particular, the use of Flex Hybrids, energy efficiency and technological innovation. The program grants tax incentives such as the exemption of IOF (Financial Operations Tax) and IPI (Tax on Industrialized Products) on electric and hybrid vehicles.	

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MACRO-CRITERIA	INDICATOR	SCORE
LIGHT BATTERY POWERED ELECTRIC VEHICLES (TRANSPORT/CROSS-SECTORAL)		
Technological	Technology readiness	5
	The technology already has a commercial scale. The main technological challenges are related to the batteries, due to the need for cheapening and increasing autonomy (65).	
	Mitigation Potential	5
	Based on the 2015 annual gasoline consumption of 30.2 billion liters (3) and considering the fuel consumption of 10 km/l in gasoline light-duty vehicles, it is estimated that in 2015 302 billion km were traveled. For a gasoline emission factor of 2,239 kg CO_2/l (18), it is estimated that emissions were 67,626.5 Gg CO_2 for the MCI vehicle fleet running on gasoline. Thus, in order to achieve the same useful service, in terms of mileage, and considering a fuel consumption of a BEV as 17.4kWh/100km and the emission factor of the electric generation of 0.4 kg CO_2/kWh, the mitigation potential of BEVs was estimated at 46,578 Gg CO_2. Equivalent to the electricity consumption of a Volkswagen e-Golf 2019 (102) and electric cars available on average (103). The emission factor of 0.4 kg CO_2/kWh is equivalent to the generation of a natural gas thermoelectric plant, conservatively simulating the electrical generation dedicated to the supply of electric vehicles. However, the ideal for emissions mitigation is that generation is from renewable sources.	
	Mitigation cost	1
	According to estimates by (68) for the U.S., the cost of purchasing Battery Electric Vehicles (BEVs) is far higher than conventional vehicles and slightly higher than Plug-in Hybrids. Much of this cost is due to the high cost of batteries, which grows with increasing autonomy, but also to indirect costs that include spending in research and development (R&D). Thus, with the expected drop in battery prices and lower R&D spending as production increases, BEVs costs will fall sharply and may be even lower than those of vehicles with internal combustion engines (ICE) by 2030. In addition to the cost of batteries, there is another factor that interferes a lot in the cost difference, which is fuel savings. Considering the total costs of 5 years of vehicle operation, the competitiveness of BEVs is reached even faster, becoming cheaper than ICE vehicles from 2025. Therefore, despite the current high acquisition cost, the prospect is for a rapid cheapening of BEVs in the next decade. According to the report of (5), the Total Cost of Ownership (TCO) of gasoline vehicles is 0.355 USD/km. For BEVs, it would be on average 0.4 USD/km. It is assumed that in 2015, gasoline vehicles drove around 302 billion km (30.2 billion liters of gasoline consumed (3) at a fuel consumption of 10 km/l). Thus, the total annual cost of BEVs (for the entire fleet) would be USD 120.8 billion, 13.6 billion more than for ICE gasoline vehicles. Finally, by dividing this cost difference by the mitigation potential of 46,578 Gg CO_2, an abatement cost of 291.8 USD/tCO_2 is estimated.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	5
	Battery electric vehicles do not emit polluting gases during operation and generate less noise than ICE vehicles.	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	**Impact on energy availability**	4
	Technology increases the energy efficiency of vehicles, reducing energy demand.	
	Jobs and income generation	4
	According to studies on electrification in Europe (69,70), there may be a reduction in jobs in the car manufacturing sector because the process of producing electric vehicles is simpler than that of ICE vehicles. However, total jobs tend to increase, because of job creation in other areas, such as: installation, operation and maintenance of recharging stations, battery production, electrical generation and distribution projects and other indirect jobs (69). Thus, it is estimated that jobs must change and adapt, obtaining a positive final balance, if vehicles are produced in the country itself. Otherwise, losses to Europe, for example, would be significant (70). For Brazil, the conventional car production chain is expected to adapt to that of electric cars and that there is the creation of a new value chain linked to electric cars, if they are assembled in the country.	
	Competitive advantages of the country	3
	It is likely that electric vehicles will not be produced in Brazil, partly by subsidies given to fossil fuels (74). Among the 694 patent applications for electric and hybrid vehicles in Brazil, only 21 are from residents in the country, 7 of which come from universities, 1 from a government research center (CPQD), 6 of companies and 7 from independent inventors; with regard to technologies, 3 are related to hybrid vehicles, 8 to electric vehicles and 10 to batteries (30). In addition, there is still no electric recharge infrastructure that meets a wide fleet of electric vehicles. On the other hand, there are several electromobility projects in the country, such as: Itaipu Binacional's VE and Mob-i Programs (7,60); the Cities Project, from Renault, which provides electric vehicles for projects in different cities (72): the Mob-i, in Foz do Iguaçu; Curitiba Ecoelétrico; the Brasilia Ecomobile; CPFL Energia's Electric Mobility Program in Campinas; a project for zero-emission transportation in Rio de Janeiro; and Celpe's Intelligent Electrical Networks Project in Fernando de Noronha. As for recharging infrastructure, companies have already invested in the installation of stations in Brazil (73), such as CPFL Energia in São Paulo, Copel in Paraná and EDP in partnership with BMW on the Presidente Dutra Highway, which connects SP to RJ. Another advantage lies in the fact that Brazil has a highly renewable electrical matrix, contributing to the possibility of electrification with low emissions.	
Institutional	**Synergy with the country's National Strategy for ST&I**	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC emphasizes the need to promote energy efficiency in vehicles (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document promotes the energy efficiency of vehicle engines and electromobility (10).	
	Feasibility of adoption under the institutional framework	4
	The Brazilian EVs market has been only following from a distance what happens in the international market. The differences in incentive to electromobility are precisely because the main motivation of other countries is to have electrification as the best solution for the decarbonization of the energy matrix, while in Brazil there are other options, such as the use of biofuels (73). However, the market has been growing, prices have been falling and the government has been giving good signs. The Rota 2030 Program (33) promotes the use of biofuels, electromobility and, in particular, the use of Flex Hybrids, energy efficiency and technological innovation. The program grants tax incentives such as the exemption of IOF (Financial Operations Tax) and IPI (Tax on Industrialized Products) on electric and hybrid vehicles.	

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MACRO-CRITERIA	INDICATOR	SCORE
BATTERY POWERED ELECTRIC BUSES (TRANSPORT/CROSS-SECTORAL)		
Technological	Technology readiness	5
	The electric bus fleet has been growing rapidly, with about 370,000 vehicles (battery and plug-in hybrids) in China alone, where there were strong subsidies (64). There are already some manufacturers in the market and growing interest from major manufacturers in developing the technology. The main challenges concern batteries and recharging methods and infrastructure (64,75,76).	
	Mitigation Potential	1
	The specific electricity consumption of Battery Electric Buses (BEBs) depends on factors such as vehicle size, number of passengers, route distance, time of year, among others (77,78). However, based on different studies (77–80), the average value of 1.6 kWh/km was stipulated. The other premises were: the 2015 road diesel consumption of about 44.8 billion liters (3); a share of buses of 19% in the fleet of diesel heavy-duty vehicles and the specific diesel consumption for buses of 3km/L (17); emission factors of 2,632 kg CO_2/L for diesel (18) and of 0.4 kg CO_2/kWh for the electrical generation. Thus, it was estimated that BEBs would reduce emissions from 22,373 Gg CO_2 to 16,320 Gg CO_2, being responsible for the mitigation of 6,053 Gg CO_2.	
	Mitigation cost	3
	The study of (76) concludes that BEBs are a little more expensive than diesel buses, costing about USD 1/km in Finland and 1.4 USD/km in California, for example, and with very low energy consumption; and that BEBs with opportunity recharging strategies are more cost-effective than those with overnight recharging. The study predicts that BEBs will become cheaper than diesel buses around 2023. However, for BEBs, there are still challenges regarding batteries and recharging infrastructure: the solution being sought in projects in Europe is quick recharging opportunity, which allows the use of smaller batteries than for night recharging, but which is complex and requires joint efforts between government and bus companies. According to the study of (76), the TCO of ICE diesel buses is approximately 0.825 USD/km. For BEBs, it would be on average 1 USD/km. It is assumed that in 2015 the ICE diesel buses drove around 25.5 billion km (8.5 billion liters of diesel consumed (3) at a specific consumption of 3 km/l). Thus, the total annual cost of BEBs (for the entire fleet) would be USD 25.5 billion, 4.4 billion more than for ICE diesel buses. Thus, by dividing this cost difference by the mitigation potential of 6,053 Gg CO_2, an abatement cost of USD 737.3/tCO_2 is estimated. For Brazil, more specifically for the state of São Paulo, the study of (81) predicted the costs for electrification of the bus fleet of the city of São Paulo, obtaining the result that BEBs would be cheaper than diesel buses for a 10-year lifetime, especially thanks to operating costs, which would have a reduction of more than 50%. Thus, the longer the lifetime and the mileage traveled annually, the more BEBs become competitive in terms of Total Cost of Ownership (TCO). The conclusion is that a diesel bus would have a TCO of 2.64 R$/km, a BEB (loading in the garage), of 2.39 R$/km (-9.5%), and a BEB (loading on the route), of 2.69 R$/km (+1.9%). According to these TCOs (81), the total annual cost of BEBs (for the entire fleet) would be USD 15.9 billion, 0.89 billion less than for ICE Diesel Buses. Thus, the abatement cost would be negative. These differences reflect the sensitivity of costs to the assumptions of battery price, recharging option (night or opportunity) and annual mileage. The 2018 EV Outlook report (64) puts that the difference between the TCO of diesel buses and BEBs would only be null or negative in cases of intense annual activity and low battery prices. Given the uncertainties presented, score 3 was given for this technology.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Physical	Health and pollution reduction	5
	Battery electric vehicles do not emit polluting gases during operation and generate less noise than ICE vehicles (81).	
	Impact on water availability	3
	The technology was considered neutral in this indicator.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Technology increases the energy efficiency of vehicles, reducing energy demand.	
	Jobs and income generation	4
	According to studies on electrification in Europe (69,70), there may be a reduction in jobs in the car manufacturing sector because the process of producing electric vehicles is simpler than that of ICE vehicles. However, total jobs tend to increase, in view of job creation in other areas, such as: installation, operation and maintenance of recharging stations, battery production, electrical generation and distribution projects and other indirect jobs (69). Thus, it is estimated that jobs must change and adapt, obtaining a positive final balance, if vehicles are produced in the country itself. Otherwise, losses to Europe, for example, would be significant (70). For Brazil, similarly to the case of light-duty vehicles, the conventional bus production chain, including parts and components, is expected to adapt to that of electric and hybrid buses (81).	
	Competitive advantages of the country	3
	It is likely that the production of electric vehicles will not be done in Brazil, partly by subsidies given to fossil fuels (74). As for the nationalization of the capacity of the entire production chain, including the production of parts and components, such as batteries, it is highly dependent on market projections because it needs investments. However, according to (81), currently it seems to be no major bottlenecks for the national production of the electric bus. Grupo Moura, Eletra and XALT Energy have partnered to produce the first 100% electric bus manufactured in Brazil, which has an autonomy of approximately 200 km (82). The Chinese automaker BYD, the largest company in the segment of electric cars and plug-in hybrids in the world, has a factory in the interior of São Paulo and already has some vehicles in operation in Brazil (83). In addition to BYD, the national capacity for the manufacture of electric and hybrid buses is divided between Eletra (São Bernardo do Campo, SP) and Volvo (Curitiba, PR). Another advantage lies in the fact that Brazil has a highly renewable electrical matrix, contributing to the possibility of electrification with low emissions.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC emphasizes the need to promote energy efficiency in vehicles (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document promotes the energy efficiency of vehicle engines and electromobility (10).	
	Feasibility of adoption under the institutional framework	4
	The Brazilian EVs market has only been following from a distance what happens in the international market. The differences in incentive to electromobility are precisely because the main motivation of other countries is to have electrification as the best solution for the decarbonization of the energy matrix, while in Brazil there are other options, such as the use of biofuels (73). Although topics related to electromobility have been raised and discussed in Brazil, there has not yet been a wide development of concrete actions or a clear direction by the institutions (81). However, the market has been growing, prices have been falling and the government has been giving some positive signals. The inclusion of CO2 vehicular emission limits in Proconve (Motor Vehicles Air Pollution Control Program) is in public consultation, which could be an important step towards electrification (81). Concerning industrial policies, the Rota 2030 Program (33) promotes the use of biofuels, electromobility and, in particular, the use of Flex Hybrids, energy efficiency and technological innovation. The program grants tax incentives such as the exemption of IOF (Financial Operations Tax) and IPI (Tax on Industrialized Products) on electric and hybrid vehicles. However, there are no specific guidelines regarding the electrification of heavy-duty vehicles. For electric, hybrid or ethanol buses manufactured in Brazil, there are more convenient financing conditions through BNDES Fundo Clima (81). As for incentives for recharging infrastructure, there are several pilot projects underway and ANEEL has already approved the regulation on the recharging of electric vehicles by those interested in providing this service (84).	

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MACRO-CRITERIA	INDICATOR	SCORE
HYDROGEN FUEL CELL ELECTRIC VEHICLES (TRANSPORT/CROSS-SECTORAL)		
Technological	Technology readiness	4
	The world fleet of Hydrogen Fuel Cell Electric Vehicles (H2FCEVs) hit about 13,000 vehicles at the end of 2018 (85). Thus, the technology is already proven, but not on a large scale of implementation. In addition, around the world there are only 376 hydrogen recharge stations in operation, what further limits the penetration and dissemination of technology (85).	
	Mitigation Potential	3
	Although there are no emissions from converting hydrogen into electricity in fuel cells, they can be significant in the production and distribution phases of hydrogen. Thus, the ideal is to combine its production with electricity from renewable sources or carbon capture projects (20,86). Based on the 2015 annual gasoline consumption of 30.2 billion liters (3) and considering the fuel consumption of 10 km/l in light-duty gasoline vehicles, it is estimated that in 2015 302 billion km were traveled. For a gasoline emission factor of 2,239 kg CO_2/l (18), it is estimated that emissions were 67,626.5 Gg CO_2 for the ICE vehicle fleet running on gasoline. For the calculation of avoided emissions, it was admitted that: hydrogen produced from electrolysis, with an efficiency of 75% (20); a specific consumption of 0.01 kg H_2/km (87); a calorific value of 120 MJ/kg H_2; emission factor of 0.4 kg CO_2/kWh for the electrical generation. Thus, the mitigation potential of H2FCEVs was estimated at 13,926.2 GgCO_2.	
	Mitigation cost	1
	Fuel Cell Electric Vehicles are the most expensive among the EVs. Comparatively, fuel cells are more expensive than batteries, hydrogen is more expensive than electricity or ethanol and costs with the supply infrastructure are also higher (20). According to the report of (5), the Total Cost of Ownership (TCO), of gasoline vehicles is 0.355 USD/km. For H2FCEVs, it would be, on average, 0.52 USD/km. In 2015, gasoline vehicles traveled about 302 billion km (30.2 billion liters of gasoline consumed (3) at a specific consumption of 10 km/l). Thus, the total annual cost of H2FCEVs (for the entire fleet) would be USD 157 billion, 49.8 billion more than for gasoline ICE vehicles. Thus, by dividing this cost difference by the mitigation potential of 13,926.2 Gg CO_2, an abatement cost of 3,578.6 USD/tCO_2 is estimated.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	5
	There is no emission of harmful gases to health (86) and there is a reduction in noise pollution.	
	Impact on water availability	2
	The demand for water for hydrogen production can reach 7l/kgH2 for methane reform and 9l/kg H_2 for electrolysis (20).	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	Impact on energy availability	4
	Technology increases the energy efficiency of vehicles, reducing energy demand.	
	Jobs and income generation	4
	For electric vehicles in general, total jobs tend to increase, because of job creation in other areas related to: the production of the vehicle and its components; recharging infrastructure; and systems and data management. Thus, it is estimated that jobs must change and adapt, obtaining a positive final balance, if vehicles are produced in the country (27,69). As for hydrogen, there may be a potential for hydrogen production in the form of hubs on the country's coast, due to its relationship with other plants and activities, such as refineries, steel production and chemical cracking plants. In addition, investments in the hydrogen chain can generate specialized jobs in the areas of technology and industry (20).	
	Competitive advantages of the country	3
	A national advantage is the electricity matrix based on renewable sources, which can lead to clean and sustainable hydrogen production (88). In terms of research centers, there is, in Rio de Janeiro, the Hydrogen Laboratory of COPPE/UFRJ, which conducts studies such as tests on plug-in hybrid buses powered by hydrogen cells and batteries, which circulate through the campus (89). There is also the Laboratory of materials and fuel cells (LaMPaC) of UFMG, which, in partnership with CEMIG, conducts research in the area of solid oxide fuel cells (90). No other initiatives were found that point to Brazil's competitive advantages.	
Institutional	Synergy with the country's National Strategy for ST&I	3
	The technology was considered neutral in this indicator.	
	Synergies with national climate policies	4
	The PNMC emphasizes the need to promote energy efficiency in vehicles (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document promotes the energy efficiency of vehicle engines and electromobility (10).	
	Feasibility of adoption under the institutional framework	1
	MCTIC included hydrogen in the CTI Plan for renewable energy and biofuels and, concerning electromobility, one of the targets of the plan is "Encouraging demonstrative projects for the use of renewable energies and fuels for the production of hydrogen for vehicular use and for the production of synthesis gas" (91). In 2016, there was also the CTCN's initiative to promote and internationalize Brazilian research in hydrogen energy, through the development, among others, of an international collaborative network and a business plan, that includes the transport sector (92). In 2018, Rio de Janeiro hosted the 22nd Global Conference on Hydrogen Energy (88). Industrial incentives can help in the development of a production chain of components of Fuel Cell Electric Vehicles in Brazil, increasing the degree of nationalization and reducing its costs. However, although there are actions in the country for the development of a hydrogen economy, there are several challenges involving its production, distribution and storage, being its main limitation the low energy density, which demands processes of compression or liquefaction. In addition, in the use and distribution phases, there are risks of leaks and explosion. Combined with this is the lack of regulation and standards for the energy uses of hydrogen, as well as bottlenecks such as the lack of investments in demonstration projects, the lack of nationalization of the production chain of equipment and components, the high costs, among others (93,94).	

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MACRO-CRITERIA	INDICATOR	SCORE
ETHANOL FUEL CELL ELECTRIC VEHICLES (TRANSPORT/CROSS-SECTORAL)		
Technological	Technology readiness	3
	The prototype of the first Ethanol Fuel Cell Electric Vehicle (EFCEVs), developed by Nissan in 2016, is in the process of economic feasibility analysis, but can be produced from 2020 in markets with ease of producing ethanol, such as Brazil (95,96). The first period of supply testing and use of the solid oxide fuel cell (SOFC) was carried out until 2017 by the manufacturer's R&D team. Later, the tests advanced to the second phase, with the use of ethanol. At this stage, Unicamp researchers, who signed an agreement with Nissan to develop technology, will do analyses, research and product development to demonstrate the viability of second-generation sugarcane ethanol in mobility (97,98). In technological terms, both ethanol reform and water-gas shift (WGS) to increase hydrogen production are technologically dominated. The challenges here refer to the SOFC, not yet completely widespread, and its integration with the reform in the vehicle, for example, that may involve providing the heat of the battery to the endothermal reform reaction. There is also the direct ethanol fuel cell (DEFC) technology, which has the advantage of being more compact and inexpensive than the one that uses the reform and produces hydrogen but has lower thermochemical conversion efficiency and still faces problems in its operation (99).	
	Mitigation Potential	5
	Ethanol reform produces a small amount of CO_2, which is emitted into the atmosphere. However, in addition to the amount being low, sugarcane growth to produce ethanol captures and stores carbon from the atmosphere, making the ethanol cycle considered emission neutral (96). Thus, the mitigation potential was considered as 67,626.5 Gg CO_2, which is the total value of emissions calculated for the ICE gasoline vehicle fleet in 2015.	
	Mitigation cost	1
	Like BEVs, it is likely that, when launched, the vehicle will have a high acquisition cost. On the other hand, its operating cost is low, comparable to that of BEVs and about a third of the cost per kilometer of a gasoline car. Another positive point is that there is no need for investment in infrastructure supply or ethanol production for Brazil. However, due to its low TRL, the achievement of the commercial level will require many investments in the development of technology and the production chain of components, which will still dictate the economic viability of the project (95). According to the report of (5), the Total Cost of Ownership (TCO) of Gasoline Vehicles is 0.355 USD/km. For Fuel Cell Electric Vehicles (FCEVs), would be on average 0.52 USD/km. Because there were no estimates for Ethanol FCEVs, the same value was considered. In 2015, gasoline vehicles were estimated to run about 302 billion km (30.2 billion liters of gasoline consumed (3) at a specific consumption of 10 km/l). Thus, the total annual cost of EFCEVs (for the entire fleet) would be USD 157 billion, 49.8 billion more than for gasoline ICE. Thus, by dividing this cost difference by the mitigation potential of 67,626.5 Gg CO_2, an estimated abatement cost of USD 737/tCO_2 is estimated.	
	Vulnerability to climate change	3
	The technology was considered neutral in this indicator.	
Physical	Health and pollution reduction	5
	There is no emission of harmful gases to health and there is a reduction in noise pollution (96).	
	Impact on water availability	4
	With the increase in the energy efficiency of the vehicle, the demand for ethanol decreases and, consequently, for water for irrigation of sugarcane plantations.	
	Impact on food production	3
	The technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	The technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Socio-economic	Impact on energy availability	4
	Technology increases the energy efficiency of vehicles, reducing energy demand.	
	Jobs and income generation	4
	For Brazil, the conventional car production chain is expected to adapt to that of electric cars and that there is the creation of a new value chain linked to electric cars, if they are assembled in the country. With regard to the country's fuel sector, it is estimated that jobs in the area of biofuels, such as ethanol, are maintained with the use of ethanol fuel cells and that in the oil area the reduction effect is not immediate (27). In addition, if the development of technology is done in the country, as has been happening with the partnership between Nissan and Unicamp, there will be the attraction of investments to research centers and generation of jobs and income. On the other hand, if vehicles are manufactured outside the country, there may be a reduction in jobs in the national automotive sector. Thus, there must be incentives for the production and national assembly of components and vehicles.	
	Competitive advantages of the country	5
	First, Brazil is one of the world leaders in ethanol production and consumption, already having the necessary infrastructure for the supply of vehicles. Therefore, Nissan chose Brazil to start the development of the technology and test its prototype, but it is not yet known whether the manufacture of the components will be national or imported. In any case, the Brazilian ethanol market will boost the development and application of technology, and vice versa (96). Unicamp's Genomics and BioEnergy Laboratory signed an agreement with the company to carry out analyses, research and the development of products and processes related to vehicular technologies and biofuels, as well as assessments of the trends of the sugar energy sector (98).	
Institutional	Synergy with the country's National Strategy for ST&I	4
	Among its objectives, the document aims to strengthen the national competitiveness of biofuels, especially ethanol (32).	
	Synergies with national climate policies	5
	The PNMC emphasizes the need to promote energy efficiency in vehicles and the use of biofuels (9). RenovaBio aims to promote and ensure the expansion of the use of biofuels, such as ethanol.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The document promotes the energy efficiency of vehicle engines, electromobility and the use of biofuels (10).	
	Feasibility of adoption under the institutional framework	5
	Brazil is strongly betting on biofuels as a solution for the decarbonization of the transport sector, which even slows the advance of incentive policies for EVs (73). Thus, the option of combining both solutions benefits from the incentive to biofuels while helping to develop electrification models. With regard to government policy signs, there is a discussion on the inclusion of CO_2 vehicular emission limits in Proconve (Motor Vehicle Air Pollution Control Program), which could be an important step towards electrification (81). Concerning industrial policies, the Rota 2030 Program (33) promotes the use of biofuels, electromobility, energy efficiency and technological innovation. The program grants tax incentives such as the exemption of IOF (Financial Operations Tax) and IPI (Tax on Industrialized Products) on electric and hybrid vehicles. Industrial incentives can help in the development of a production chain of components of Electric Vehicles to Fuel Cell in Brazil, increasing the degree of nationalization and reducing its costs.	

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MACRO-CRITERIA	INDICATOR	SCORE
	GENERATION OF ELECTRICITY FROM BIOGAS WITH MICROTURBINES (WASTE/EFFLUENTS, MSW AND AGRICULTURAL)	
Technological	Technology Readiness	4
	This technology has already been tested and approved under operating conditions in several countries, but in Brazil the initiatives are still modest and not focused on equipment manufacturing. There is a need to develop a national market for microturbines, especially for biogas utilization (1,2).	
	Mitigation potential	1
	Accumulated mitigation potential for landfill biogas production was presented in the document "Low Carbon Options Sector Modeling for the Waste Management Sector" (3). The accumulated potential was converted on an annual basis totaling 3,792 Gg CO_2. According to the methodology adopted, it fits in the potential range with score 1.	
	Mitigation cost	4
	The document "Low Carbon Options Sectoral Modeling for the Waste Management Sector" presents negative costs for the landfill biogas energy production, which would place this technology in scoring category 5. However, microturbines have higher costs than internal combustion engines and conventional turbines and also require importation. For this reason, a lower score was considered (score 4).	
	Vulnerability to climate change	3
	This technology is considered neutral in this indicator.	
Physical	Health and pollution reduction	4
	Microturbines have lower NOx emissions compared to internal combustion engines (4,5).	
	Impact on water availability	3
	This technology is considered neutral in this indicator.	
	Impact on food production	3
	This technology is considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	The produced electric energy can be used in the own generating plants or commercialized (6).	
	Jobs and income generation	4
	Energy utilization of waste requires an efficient system of collection, transport and categorization/separation. Structuring this productive chain promotes the generation of jobs for the design, construction and operation of power plants, as well as for the stages of collection and separation of waste. In addition, the commercialization or utilization of the energy produced can generate income for the producing units.	
	Competitive advantages of the country	2
	Considering the existing estimates, Brazil only exploits 7% to 20% of biogas produced from waste for energy purposes (7). In addition, there is a difficulty in accessing microturbines in Brazil, which need to be imported (1,3).	
Institutional	Synergy with the country's National Strategy for ST&I	4
	It is compatible with the strategic energy theme, which incentives the production of bioenergy and biofuels as a way to reduce GHG and air pollutant emissions from the recovery of urban, industrial and agricultural waste (8).	
	Synergies with national climate policies	5
	Biogas is highlighted in the RenovaBio Program and also in the National Climate Change Plan (9,10).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	It is compatible with strategic axis II (sustainable infrastructure), in which the use of biogas produced from waste is considered an alternative for renewable energy generation (11).	
	Feasibility of adoption under the institutional framework	4
	The use of biogas for electricity generation is one of the guidelines of the National Solid Waste Policy, established in 2010 (12), however, there is a lack of funding nerworks, regulatory framework and specific incentives for biogas projects (13). In addition, the unavailability of equipment in the domestic market makes it difficult to spread this technology in the country.	

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MACRO-CRITERIA	INDICATOR	SCORE
BIODIGESTION OF MSW FOR GENERATING ELECTRICITY AND BIOMETHANE (WASTE/MSW)		
Technological	**Technology Readiness**	5
	Mature technology applied in many countries (13–15).	
	Mitigation potential	1
	Accumulated mitigation potential for MSW biodigestion in the document "Low Carbon Options Sector Modeling for the Waste Management Sector" (3). The accumulated potential was converted on an annual basis (889 Gg CO_2eq) and, according to the methodology described, it falls within the potential range with score 1.	
	Mitigation cost	4
	The document "Low Carbon Options Sector Modeling for the Waste Management Sector" (3) presents costs of USD 0.37-0.45/tCO_2 for MSW biodigestion, which would place such technology in the category with score 4.	
	Vulnerability to climate change	3
	This technology is considered neutral in this indicator.	
Physical	**Health and pollution reduction**	4
	Energy utilization of biogas produced by biodigestion for electricity generation may cause NOx emission, but in low quantities.	
	Impact on water availability	3
	This technology is considered neutral in this indicator.	
	Impact on food production	3
	This technology is considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is considered neutral in this indicator.	
Socio-economic	**Impact on energy availability**	4
	This technology promotes the generation of electricity and biomethane, which can be used in plants or traded (6).	
	Jobs and income generation	4
	Energy utilization of waste requires an efficient system of collection, transport and categorization/separation. Structuring this productive chain promotes job creation for the design, construction and operation of the biodigesters, as well as for the collection and separation stages. In addition, the commercialization or use of energy and biomethane can generate income for the producing units.	
	Competitive advantages of the country	2
	There are some plants in operation in Brazil, however such technology is implemented in a small scale in the country (16). Several biodigestion projects have been implemented and abandoned, mainly due to the use of inadequate materials and lack of technical assistance (13).	
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	The technology is compatible with the strategic energy theme, which incentives the development of bioenergy and biofuels from urban, industrial and agricultural waste (8).	
	Synergies with national climate policies	5
	Biogas is highlighted in the RenovaBio Program and also in the National Climate Change Plan (9,10).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	It is compatible with the strategic axis II (sustainable infrastructure), in which the use of biogas energy from waste is considered as an alternative for renewable energy generation (11).	
	Feasibility of adoption under the institutional framework	4
	Energy use of biogas is one of the guidelines of the National Policy on Solid Waste, established in 2010 (12), however, there is a lack of funding networks, regulatory framework and specific incentives for biogas projects (13).	

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MACRO-CRITERIA	INDICATOR	SCORE
WASTE INCINERATION (WASTE/MSW AND AGRICULTURAL)		
Technological	Technology Readiness	5
	The technology is developed and applied in several countries, such as USA, Japan and European countries (17).	
	Mitigation potential	1
	Accumulated mitigation potential for MSW biodigestion is presented in the document "Low Carbon Options Sector Modeling for the Waste Management Sector" (3). The accumulated potential has been converted an annual basis (95 Gg CO_2eq) and, according to the methodology adopted, fits into the potential range with score 1.	
	Mitigation cost	3
	The document "Low Carbon Options Sector Modeling for the Waste Management Sector" has costs of USD 15.48 - 23.61/tCO_2 for MSW incineration, which fits the technology into the cost range with score 3.	
	Vulnerability to climate change	3
	This technology is considered neutral in this indicator.	
Physical	Health and pollution reduction	2
	Incinerators produce various air pollutants such as particulate matter, NOx, acid gases, heavy metals, dioxins and furans. Modern incinerators already have lower pollutant emissions and treatment systems. However, there is an increase in emissions of these same compounds in the incinerator waste system (3,18,19).	
	Impact on water availability	3
	This technology is considered neutral in this indicator.	
	Impact on food production	3
	This technology is considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Waste incineration has potential for energy recovery for electricity generation, which can be harnessed at the incinerator plants themselves (20).	
	Jobs and income generation	4
	Waste recovery requires an efficient collection, transport and categorization/separation system, especially for incineration, which requires high material specification. Structuring this productive chain promotes job creation for the design, construction and operation of the incinerator plants, as well as for the collection and separation stages. In addition, the commercialization of energy and inert ash produced generates income for these units (21).	
	Competitive advantages of the country	3
	In Brazil there are few incinerator plants and most of them are used to treat health and extraordinary waste. Currently the company Usina Verde, located at the Federal University of Rio de Janeiro, is a pioneer in the development of the technology for Solid Waste Energy Recovery Plants (URE), and holds patents for the incineration process (22). However, the country does not offer competitive advantages in the international scenario.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	It is compatible with the strategic energy theme. The strategy incentives reducing GHG and air pollutant emissions by harnessing urban, industrial and agricultural waste (8).	
	Synergies with national climate policies	5
	The National Climate Change Plan (PNMC) highlights incineration with energy recovery as an alternative for reducing emissions from the waste sector (10).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	Although not directly mentioned in the GCF Country Program, incineration is an alternative for energy waste that fits into strategic axis III (sustainable infrastructure) (11).	
	Feasibility of adoption under the institutional framework	4
	Waste incineration is presented in the guidelines of the National Solid Waste Policy, established in 2010 (12). However, concerns about polluting gases treatment, especially heavy metals, have discouraged the development of this technology (3).	

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MACRO-CRITERIA	INDICATOR	SCORE
PLASMA GASIFICATION OF MSW (WASTE/MSW)		
Technological	Technology Readiness	4
	Although plasma technologies have a high level of maturity (above 6), their application for waste treatment and/or recovery still needs investment in R&D, especially in process simulation and modeling (19). Some companies, such as Westinghouse, Europlasma, Tetronics and Phoenix Solutions Company (PSC), have already developed industrial waste power plants using plasma technology (23). Thus, this technology has already been tested and qualified under operating conditions (TRL 8).	
	Mitigation potential	1
	Plasma waste treatment has higher emission mitigation potential than incineration technology (24). However, according to the methodology used to evaluate the mitigation potential and considering that both technologies are based on the thermal treatment of waste, both were considered to have the same mitigation potential.	
	Mitigation cost	1
	Plasma gasification technology is more expensive than conventional gasification and incineration (25–27). This technology has high capital costs, especially for larger scale applications (25).	
	Vulnerability to climate change	3
	This technology is considered neutral in this indicator.	
Physical	Health and pollution reduction	5
	Technology reduces emissions of air pollutants, such as NO_x e SO_x (19,27).	
	Impact on water availability	3
	This technology is considered neutral in this indicator.	
	Impact on food production	3
	This technology is considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is considered neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Plasma gasification waste treatment can produce electrical energy or the synthesis gas can be used for fuel, chemical or pure hydrogen production (23,24,26).	
	Jobs and income generation	4
	Energy utilization of waste requires an efficient system of collection, transport and categorization/separation. Structuring this productive chain promotes job creation for the design, construction and operation of plasma gasification plants, as well as for the collection and separation stages. In addition, the use or commercialization of the energy sources and the vitrified slag produced promotes additional income generation for these units.	
	Competitive advantages of the country	3
	The Aeronautics Technology Institute (ITA) has a plasma technologies research center (28). Projects for the development of waste plasma gasification plants in the cities of Hortolândia (SP) and Planaltina (DF) were approved, but no recent data on their implementation were found (29). For this reason, it was considered that, in general, Brazil does not have significant competitive advantages for the development of this technology for waste treatment. Thus, the technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	4
	It is compatible with the strategic energy theme, which incentives the reduction of GHG and air pollutant emissions by harnessing urban, industrial and agricultural waste (8).	
	Synergies with national climate policies	4
	Although this technology is not directly mentioned in national climate policies, it is based on the heat treatment of energy-efficient waste, as well as incineration, which was highlighted in the PNMC (10).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	Although not directly mentioned in the GCF Country Program, plasma gasification is an alternative for energy waste that fits into strategic axis III (sustainable infrastructure) (11).	
	Feasibility of adoption under the institutional framework	4
	This technology is not directly supported by any institution or regulation. However, PNRS groups a set of instruments, goals and actions focused on integrated solid waste management. In addition, PNRS encourages the development of systems and technologies for the treatment and energy recovery of waste (12).	

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MACRO-CRITERIA	INDICATOR	SCORE
USE OF AGRICULTURAL AND AGRO-INDUSTRIAL WASTE (WASTE/AGRICULTURAL)		
Technological	Technology Readiness	5
	The technology is already developed on an industrial scale in the country (30). The challenge remains, however, of dealing with the seasonality of raw materials through the technological mastery of the co-digestion process.	
	Mitigation potential	4
	The mitigation potential was determined considering the use of vinasse and agricultural residues (18,010 Gg CO_2eq). To calculate the mitigation potential from vinasse utilization, the emission factors of vinasse presented in Salomon (2007) (31) and ethanol production of 2017 (32) were used. The mitigation potential of agricultural waste for electricity generation was presented in Portugal-Pereira (2015) (33).	
	Mitigation cost	3
	According to Manochio (2015) and Moraes et al. (2014) mitigation cost for energy production from vinasse is USD 13-16/tCO_2 (34,35). According to the adopted methodology, this cost fits in the range with score 3.	
	Vulnerability to climate change	4
	The use of agricultural residues allows greater diversification of energy sources in a climate change context.	
Physical	Health and pollution reduction	3
	This technology is considered neutral in this indicator.	
	Impact on water availability	5
	Vinasse utilization eliminates the risks of groundwater and water courses contamination by its direct application to the soil (30).	
	Impact on food production	5
	Biodigested vinasse can be used as fertilizer and avoids temporary soil acidification by the direct application of vinasse (36). Regarding crop residues, part of them must be left on the plantations to protect the soil against erosion, retain moisture and recycle nutrients lost during harvesting (37).	
	Impact on biodiversity conservation	4
	By avoiding the impacts associated with vinasse direct application to soils, it can be concluded that its use positively impacts biodiversity.	
Socio-economic	Impact on energy availability	4
	The energy produced by vinasse and agricultural residues can be used in the plants and agricultural units themselves or sold. There is also the possibility of using agricultural residues to produce biofuels and other products.	
	Jobs and income generation	4
	Generation of jobs in the construction stage of vinasse and agricultural waste utilization units. Jobs also are generated in creating a waste supply chain, which involves stages of collection, transportation and processing. Thus, local economies are stimulated, promoting income generation.	
	Competitive advantages of the country	5
	Brazil has a great competitive advantage because it is a large agricultural producer and has high potential for the energtic use of waste (33,37). It is also one of the world's largest producers of ethanol and therefore vinasse. Universities and research centers like the São Carlos School of Engineering (EESC), the University of São Paulo (USP) and the National Bioethanol Science and Technology Laboratory (CTBE) of the National Center for Energy and Materials Research (CNPEM), have projects focused on the use of vinasse (38).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	**Synergy with the country's National Strategy for ST&I**	4
	The utilization of vinasse and agricultural waste fits into the strategic themes of energy and biomes and bioeconomy. The strategy defends the development of more sustainable industrial processes, especially in the use of agricultural/agro-industrial and urban waste for energy production and reduction of environmental impacts (8).	
	Synergies with national climate policies	5
	The energy production from vinasse and agricultural waste is compatible with the goals of the NDCs, as it increases the participation of sustainable bioenergy in the Brazilian energy matrix (39). In addition, the application of this technology will enable the plants to participate in the RenovaBio program (9).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	It is compatible with strategic axes I (Agriculture and Forests) and II (Sustainable Infrastructure). The program incentives the investment in technologies that take advantage of alternative energy sources such as ethanol and sugar production wastes, urban solid wastes and agricultural wastes (11).	
	Feasibility of adoption under the institutional framework	3
	So far, no information has been found on legal instruments, taxes and institutions that encourage the use of vinasse and agricultural waste in Brazil. Also, logistic and economic issues are associated with the utilization of agricultural waste. The need to establish a logistics chain for waste collection and transportation implies the restructuring of rural activities and adds costs to the productive process.	

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MACRO-CRITERIA	INDICATOR	SCORE
	PHOTOVOLTAIC SOLAR INDUCTION STOVES (BUILDINGS/RESIDENTIAL)	
Technological	Technology Readiness	5
	Modern solar cookers work with solar energy, associated with a battery and photovoltaic panel, usually installed on the roof of buildings. They have wide technological availability, leaving the challenge of applying them in every possible scale and dimension.	
	Mitigation potential	1
	This technology is an alternative to cooking using firewood in rural areas. Its GHG mitigation potential is little significant at the national level, being more relevant for reducing local pollution.	
	Mitigation cost	5
	In view of the total emission reduction compared to wood stoves, this technology was scored with the highest score in this indicator (1).	
	Vulnerability to climate change	2
	The operation of the technology depends on the incidence of sunlight. Climate change may affect resource availability and intensity.	
Physical	Health and pollution reduction	5
	Solar stoves are an alternative to wood stoves, used mainly in rural areas and isolated regions of the country, which cause the emission of pollutant gases in homes and cause health problems to the population. (2).	
	Impact on water availability	3
	This technology was considered neutral in this indicator.	
	Impact in food production	3
	This technology was considered neutral in this indicator.	
	Impact on biodiversity conservation	3
	Using this technology in isolated locations replaces the use of firewood and reduces forest degradation caused by logging (2).	
Socio-economic	Impact on energy availability	5
	Renewable and clean energy for rural families to replace firewood, sticks and other cooking materials (2–4).	
	Jobs and income generation	4
	Employment generation in the equipment manufacturing stage and construction of an associated production chain. Income generation occurs through increased availability of rural inhabitants, who spend a lot of time collecting firewood, to perform paid activities (2).	
	Competitive advantages of the country	5
	The country has high resource availability. UFRN research centers have already manufactured solar cooker models that have proven their viability to replace both the use of firewood and gas canisters (4). Currently a company manufactures and markets solar cookers in Brazil (5).	
Institutional	Synergy with the country's National Strategy for ST&I	4
	Technology is not directly cited in the national CTI strategy but fits into the strategic energy theme that encourages R&D actions for renewable energy sources. (6).	
	Synergies with national climate policies	4
	The technology is not directly cited in national climate policies but fits within the NDC's proposals to encourage renewable sources and the expansion of domestic use of non-fossil energy sources. (7,8).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	Technology is not directly cited in the program, but fits into strategic axis III (Resilient cities, communities and territories), which encourages the development of housing solutions that increase the resilience and sustainability of the low-income population, indigenous peoples and traditional communities (9).	
	Feasibility of adoption under the institutional framework	3
	To date, no information has been found on legal instruments, taxes and institutions that stimulate the development of solar cookers in Brazil. Moreover, cultural issues are associated with the development of this technology, due to the difficulty of adapting the rural population to the new technology and the impossibility of using it at night.	

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MACRO-CRITERIA	INDICATOR	SCORE
RENEWABLE MICROGENERATION PLANTS: WIND MICROTURBINES, OPV AND THIN FILM CELLS (BUILDINGS/RESIDENTIAL, COMMERCIAL AND SERVICES)		
Technological	Technology Readiness	4
	Wind turbines and silicon photovoltaic panels have high technological maturity (TRL 9). However, more innovative technologies such as organic photovoltaic cells (OPV) and thin film photovoltaic panels have limited efficiency and are under development for industrial scale production. References indicate a level of technological readiness in the TRL range 6-8 (10–13).	
	Mitigation potential	1
	The mitigation potential was calculated, assuming that all energy consumption in the building sector would be met by renewable microgeneration. Therefore, the mitigation potential considered is equivalent to the sector emissions and was calculated from the sector energy consumption in 2015 (14) and grid emission factor (15). According to the methodology adopted, the mitigation potential (8.36 Gg CO_2) fits in the potential range with score 1.	
	Mitigation cost	1
	Costs were estimated based in (16) and represent the average Mitigation cost for photovoltaic generation in the five Brazilian regions (USD 4,790/tCO_2).	
	Vulnerability to climate change	1
	Climate change may impact the availability of renewable resources and the efficiency of photovoltaic panels and thermal machines (17,18).	
Physical	Health and pollution reduction	4
	Substitution of fossil energy sources that emit atmospheric pollutants and negatively impact human health.	
	Impact on water availability	3
	Renewable energy sources as solar and wind require much less water than conventional fossil sources. Applications of these technologies for desalination and water pumping may increase the supply of drinking water (19). Although such positive effects can be observed by the use of renewable sources, it was generally considered that this technology is neutral in this indicator.	
	Impact on food production	3
	This technology is neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	Power generation occurs at the consuming units themselves (buildings), reducing the total energy demand of the SIN and transmission and distribution losses (19,20).	
	Jobs and income generation	4
	The development of microgeneration technologies through renewable energy sources requires the training of skilled labor for R&D, equipment manufacturing, design, installation and maintenance of systems. The manufacturing and service industry represent a large part of employment opportunities, which promotes income generation and positive impacts on local economies. (21).	
	Competitive advantages of the country	4
	The country has large availability of solar and wind resources for microgeneration (22).	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	5
	Microgeneration fits into the strategic themes of energy and climate. The national CTI strategy defends the development of a renewable energy technology institute, with an initial focus on creating a renewable energy testing and demonstration center to strength these technologies in the national territory (6).	
	Synergy with national climate policies	5
	Renewable microgeneration are encouraged by diverse national climate policies. The PNMC defends the development of distributed generation as an alternative to reduce transmission and distribution losses and provide reliability to the electrical system. For the building sector, PNMC recommends the development of renewable energy (23). The NDCs propose 45% share of renewable sources in energy matrix by 2030 (8) .	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	Microgeneration fits into strategic axis II (Sustainable Infrastructure). The program defends prioritizing alternatives that focus on diversifying the energy matrix, especially from renewable sources such as photovoltaic and wind generation (9).	
	Feasibility of adoption under the institutional framework	5
	ANEEL Normative Resolution 482/2012 states the general conditions for distributed micro-generation and mini-generation access to electricity distribution systems (24). In addition, there are institutional programs in the country such as MME's ProGD (Distributed Generation of Electric Energy Development Program), which aims to promote the expansion of distributed generation in buildings and ANEEL's Inova Energia Plan, which aims to coordinate actions to promote innovation and improve the integration of support instruments provided by BNDES, ANEEL and FINEP for the development and technological expertise in alternative renewable energies in Brazil (25,26). Tax incentives such as exemption from ICMS, IPI and the inclusion of solar and wind generation equipment in the "Mais Alimentos" Program, which enables lower interest rates for financing, can stimulate the implementation of renewable microgeneration in buildings (27).	

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MACRO-CRITERIA	INDICATOR	SCORE
SMART GRIDS (BUILDINGS/RESIDENTIAL, COMMERCIAL AND SERVICES)		
Technological	Technology Readiness	3
	The development of smart grids is associated with the adoption of energy policies. Initiatives have been demonstrated in several countries (28,29). In Brazil, smart grids are still in the early stages of implementation, with some pilot projects underway. Overall, this technology is in an accelerated process of development (30). For this reason, a technology readiness level of 6 was considered, which indicates that the technology is being tested in an operating environment.	
	Mitigation potential	1
	There is a difficulty in quantifying the GHG mitigation potential associated with the implementation of smart grids. However, given that the building sector is the least significant in the context of national emissions and the low grid emission factor, it was considered that this technology has low mitigation potential. (31).	
	Mitigation cost	1
	Deployment of smart grids is associated with high investment in smart meters, TI infrastructure and telecommunication (30). According to (32), the accumulated investment until 2030 for the adoption of smart grids in Brazil is between R$ 44 to 83 billion. Also, according to (33), the levelized costs of smart grids in Brazil range from 5.2 to 6.7 thousand R$/MWh by 2030. Considering a grid emission factor of 0.124 tCO_2/MWh (15), levelized costs range from R$ 647/tCO_2 to R$ 834/tCO_2 (208 a 268 USD/tCO_2).	
	Vulnerability to climate change	3
	This technology is neutral in this indicator.	
Physical	Health and pollution reduction	3
	This technology is neutral in this indicator.	
	Impact on water availability	3
	This technology is neutral in this indicator.	
	Impact on food production	3
	This technology is neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is neutral in this indicator.	
Socio-economic	Impact on energy availability	5
	Smart grids enhance the quality of energy services by decreasing the number and duration of power outages and making electricity more efficient (via superconductive cables). They also reduce the dependence of large power plants on grid supply, as they allow the use of small power plants (opportunity for renewable microgeneration), facilitate the varied use of energy (by supplying hybrid vehicles) and reduce the frequency of power thefts (30,33,34).	
	Jobs and income generation	5
	Smart grids encourage job and income generation by stimulating the creation of a national smart meter manufacturing industry and generating incentives to reduce peak hour energy consumption (33).	
	Competitive advantages of the country	3
	The country has no competitive advantages for the development of smart grids. In Brazil, distribution networks are based on conventional technologies with limited level of automation and are subject to weather and vegetation conditions (35). In addition, there is a need to develop the industrial capacity in order to supply the market with the necessary technologies.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	5
	Smart Grids fit the strategic energy theme, which proposes the development of technologies associated with smart grids, new energy transmission and distribution and storage technologies, aiming at greater security of the SIN (6).	
	Synergies with national climate policies	4
	Smart grid technologies are not directly cited in national climate policies, but are in line with the PNMC targets for reducing non-technical losses in power distribution and adopting an integrated planning system that enables energy efficiency gains. (23).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not directly cited in the GCF Country Program, but is in line with the strategic axis II (Sustainable Infrastructure) and III (Resilient Cities, Communities and Territories), which aim to use more efficient materials and technologies in the building sector (9).	
	Feasibility of adoption under the institutional framework	4
	Some institutions have launched programs to encourage the development of smart grids in the country. ANEEL has launched the Brazilian Intelligent Grid Program which aims to foster the technological migration of the Brazilian electric sector to fully adopt the concept of intelligent grids throughout the country (36,37). The ABDI (Brazilian Agency for Industrial Development) structured a thematic project on information and communication technologies focusing on mapping the supply chain of products and services for smart grids (38). In 2018 a senate law (PLS 356/2017) that encourages the modernization of public utility distribution facilities with new smart grid architecture was approved by the Senate Infrastructure Services Commission (CI) (39,40).	

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MACRO-CRITERIA	INDICATOR	SCORE
NEW MATERIALS FOR ZERO ENERGY BUILDINGS (BUILDINGS/RESIDENTIAL, COMMERCIAL AND SERVICES)		
Technological	Technology Readiness	3
	ZEBs imply a profound transformation in the construction industry and the availability of efficient technologies in the market (41). Some materials represent technologies currently developed and available (green roofs, green plaster, reflective roofs, thermal insulation systems, floor heating and efficient lighting and ventilation systems) (42–44). However, more innovative solutions such as phase change materials (PCMs), kinetic facades, thermoelectric materials with varying conductivity and new generations of selective glasses are still under development (45–47). For this reason, an average technological readiness level equivalent to TRL 6-7 was considered.	
	Mitigation potential	1
	New materials for ZEBs do not include distributed generation (GD), innovations in materials already considered in the industrial sector and non-innovative technologies such as green roofs and efficient light bulbs, for example. The low grid emission factor and the fact that this technology is part of a sector that is not so expressive in the national emissions (31), justify their low mitigation potential.	
	Mitigation cost	3
	Some materials represent low and medium cost solutions, such as green roofs, green plaster, efficient lamps and ventilation systems, for example. But more innovative alternatives, such as PCMs, kinetic facades, thermoelectric materials with varying conductivity and new generations of selective glass, have high costs. For this reason, it was considered that, on average, the score of this technology according to the cost indicator has an intermediate value (45–47).	
	Vulnerability to climate change	3
	This technology is neutral in this indicator.	
Physical	Health and pollution reduction	3
	This technology is neutral in this indicator.	
	Impact on water availability	3
	This technology is neutral in this indicator.	
	Impact on food production	3
	This technology is neutral in this indicator.	
	Impact on biodiversity conservation	3
	This technology is neutral in this indicator.	
Socio-economic	Impact on energy availability	4
	New materials for the ZEBs enable the energy consumption of buildings to be reduced. In addition, the integration of ZEBs with electric vehicles allows them to function as energy storages, stocking up any excess energy generated (from renewable sources), which will be used at times when energy demand in buildings exceeds local production (48).	
	Jobs and income generation	5
	Job creation is associated with the creation of new products and the establishment of their productive chains, which in turn stimulate the local economy and generate income. There is also the generation of qualified jobs for the R&D of new materials and in the construction sector. Moreover, the reduction in energy consumption due to the use of these materials increases the availability of income.	
	Competitive advantages of the country	3
	Brazil has no significant initiatives for the development of ZEBs and SEBRAE is a reference institute in ZEBs research. Countries like the United States, France, Germany and Australia lead the ZEB market (49). For this reason, this technology was considered neutral in this indicator.	

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	4
	Innovations in materials for ZEBs fit in the theme of converging and enabling technologies of the national CTI strategy, which encourages the development of advanced and sustainable materials (6).	
	Synergy with national climate policies	4
	Innovations in materials for ZEBs are compatible with the PNMC which emphasizes the implementation of programs to regulate the energy efficiency of buildings and cover aspects such as lighting, air conditioning and building envelope (23).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The new materials for the ZEBs are compatible with the strategic axes II (sustainable infrastructure) and III (Resilient Cities, Communities and Territories) of the GCF Country Program, which proposes the use of more efficient materials in housing and buildings (9).	
	Feasibility of adoption under the institutional framework	4
	Certifications applied to buildings such as PROCEL Buildings Seal and Brazil Zero Energy LEED and GBC (Green Building Council) certificates can stimulate the development of new materials for ZEBs in Brazil. The PROCEL Buildings Seal is a voluntary membership instrument that aims to identify buildings with high energy efficiency ratings. In the certification process, the building systems of envelope, illumination, conditioning and water heating are evaluated (50). The Leadership in Energy and Environmental Design (LEED) certificate is an international building certification and environmental guidance system that aims to encourage sustainable transformation. The aspects evaluated in the certification stages include materials and resources, water efficiency, innovation and processes (51). The GBC Brasil Zero Energy certification is a tool that aims to boost the development of ZEBs and the transformation of existing buildings (52). While such initiatives are useful in stimulating the reduction of energy consumption in buildings and ZEBs, they do not focus on developing new materials.	

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MACRO-CRITERIA	INDICATOR	SCORE
PRECISION AGRICULTURE (AFOLU/AGRICULTURE)		
Technological	Technology Readiness	4
	The technology is already developed globally; however, it is not widely applied in Brazil.	
	Mitigation potential	4
	The expansion of precision agriculture has a relevant potential in CO_2 removal by reducing fertilizer application (indirect emissions). However, it is not possible to state that there will be direct and short-term benefits in areas managed under precision farming techniques since this result will depend on the variability found in each area, technology, and management solutions employed, among other variables (1).	
	Mitigation cost	3
	The cost varies within a wide range. In this sense, the median was chosen according to the normalization of costs, which implies neutrality in the indicator.	
	Vulnerability to climate change	4
	Given that one of the objectives of precision agriculture is to rationalize the use of agricultural inputs, the development of optimized systems capable of integrating productivity maps and climate data (forecasting and monitoring) allows internalizing climate risks in agricultural management.	
Physical	Health and pollution reduction	4
	Controlling the application of potentially polluting agricultural inputs such as fertilizers, concealers, and pesticides (herbicides, fungicides, insecticides, etc.) to each site can reduce environmental impacts, including reducing pollution.	
	Impact on water availability	4
	The precision irrigation can reduce the use of water resources based on the data obtained by sensors that measure the effective need of the crops, thereby increasing the availability of water for other uses.	
	Impact on food production	4
	The technology application is expected to increase food production.	
	Impact on biodiversity conservation	2
	The application of precision agriculture is more prevalent in monocultures than in diversified crops, thus negatively affecting biodiversity.	
Socio-economic	Impact on energy availability	4
	The expected benefits of adopting precision agriculture include a significant increase in crop productivity, including in the sugarcane industry. In addition to sugarcane production, ethanol can be used for energy purposes.	
	Jobs and income generation	2
	The technology implies process automation, thus leading to less use of the workforce.	
	Competitive Advantages of Brazil	5
	Brazil is one of the world's largest agricultural producers and the expansion of precision agriculture could increase production efficiency and save resources. Therefore, the impacts arising from such competitive advantages would be very relevant.	

continues

continuation

MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	5
	The technology has strong synergy with the national strategy in science, technology and innovation (Encti) (2). The strategy's "Foods" theme highlights the importance of focusing efforts on automation and precision agriculture.	
	Synergies with national climate policies	4
	Precision agriculture is not made explicit in national climate policy, but it has synergy with the principle of "Strategy for Sustainable Development in Agriculture" of Nationally Determined Contribution (NDC) (3).	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not made explicit in the document, but has strategic synergy with Axis 3.1 - Agriculture and Forestry (3.1.3: Agriculture low-carbon and adaptation in the productive sector) (4)particularly when it comes to actions in the area of agriculture, it should focus on promoting emission-mitigating agricultural technologies in already anthropized areas that encourage the adoption of conservationist systems and practices and reduce the vulnerability of agricultural systems to climate change.	
	Feasibility of adoption under the institutional framework	4
	Given the Brazilian institutional framework and its instruments, it is observed that there is feasibility for the development and expansion of technology, in particular PL 149/2019, which deals with the "National Policy of Incentive for Precision Agriculture". However, greater efforts are required for its implementation in the national agricultural context.	

continues

continuation

MACRO-CRITERIA	INDICATOR	SCORE
CARBON ALTERNATIVES TO NITROGEN, PHOSPHORUS AND POTASSIUM (AFOLU/AGRICULTURE)		
Technological	Technology Readiness	2
	The technology is not fully developed in Brazil.	
	Mitigation potential	4
	The alternative has relevant mitigation potential due to the expected reduction in synthetic fertilizer application (5).	
	Mitigation cost	3
	The cost varies within an extensive range given the technological options included in this measure. In this sense, the median was chosen according to the normalization of costs, which implies neutrality in the indicator.	
	Vulnerability to climate change	3
	Technology is considered neutral in this criterion as it does not show vulnerability to the expected effects of climate change.	
Physical	Health and pollution reduction	4
	The application of technology involves reducing the use of synthetic fertilizer inputs, leaching, and lower GHG emissions.	
	Impact on water availability	3
	The technology is considered neutral in this criterion as it has no impact on water availability.	
	Impact on food production	4
	The technology is an alternative to the use of agrochemicals, many of which are imported, contributing to food security.	
	Impact on biodiversity conservation	4
	The technology can reduce ecosystem contamination due to the replacement of conventional (synthetic) fertilizers.	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral in this criterion	
	Jobs and income generation	3
	The technology is considered neutral in this criterion	
	Competitive Advantages of Brazil	5
	Brazil is one of the world's largest agricultural producers and 77% of NPK components are imported. Thus, the development of this technology can significantly increase the country's agricultural competitive advantages by reducing production costs.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not made explicit in Encti, but it has synergy and may be appropriate to the strategic theme "Food", in particular, the strategy associated with "Strengthening research in frontier knowledge areas (biotechnology, bioinformatics, nanotechnology, modeling, simulation, and automation" aiming at increasing productivity, adapting to climate change and agricultural defense ".	
	Synergies with national climate policies	4
	The technology has synergy with the ABC Plan (6), as it relates to Biological Nitrogen Fixation.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not made explicit in the document, but has synergy with Strategic Axis 3.1 - Agriculture and Forests (3.1.3: Low carbon agriculture and adaptation in the productive sector), particularly when it comes to actions in the area of agriculture that should focus on promoting emission-mitigating agricultural technologies in already anthropized areas that encourage the adoption of conservationist systems and practices and reduce the vulnerability of agricultural systems to climate change.	
	Feasibility of adoption under the institutional framework	4
	The country has a legal framework for technology implementation, but adaptations are required for its expansion.	

continues

continuation

MACRO-CRITERIA	INDICATOR	SCORE
AGRICULTURAL GENETIC IMPROVEMENT WITH ROBOTIC PHENOTYPING (AFOLU/AGRICULTURE)		
Technological	Technology Readiness	4
	Agricultural genetic improvement is a globally widespread technology, with room for further national diffusion. New advances at the frontier of knowledge about organisms adapted to the effects of climate change and the long-term effects that genetically modified organisms (GMOs) have on human health and biodiversity may benefit the technology's maturity.	
	Mitigation potential	4
	This technology has relevant mitigation potential due to the expected reduction of fertilizer application.	
	Mitigation cost	3
	The cost varies within an extensive range given the technological options included in this measure. In this sense, the median was chosen according to the normalization of costs, which implies neutrality in the indicator.	
	Vulnerability to climate change	4
	There is the possibility of crops adapted to climate changes (resistant to high temperatures, water scarcity, etc.).	
Physical	Health and pollution reduction	3
	Technology implies equivalent benefits and trade-offs, which is why it is neutral on this criterion.	
	Impact on water availability	4
	The technology reduces the water demand in crops.	
	Impact on food production	4
	It implies increasing agricultural production, as well as food with higher energy use and that has greater durability.	
	Impact on biodiversity conservation	2
	Genetically modified crops can cause biodiversity reduction.	
Socio-economic	Impact on energy availability	4
	Agricultural productivity gains may favor increased biofuel production.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive Advantages of Brazil	5
	Brazil is one of the world's largest agricultural producers and the implementation of technology can further enhance the country's competitive advantages.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not made explicit in Encti, but has synergy and may be appropriate to the strategic theme "Food", in particular the strategy associated with "Strengthening research in frontier knowledge areas (biotechnology, bioinformatics, nanotechnology, modeling, simulation and automation") aiming at increasing productivity, adapting to climate change and agricultural defense ".	
	Synergies with national climate policies	4
	The technology is not made explicit in national climate policies, but has synergy with the ABC Plan, in particular related to "Adaptation to climate change", and the RenovaBio project (7), regarding "... promoting proper expansion biofuels in the energy matrix, with emphasis on the regularity of fuel supply ".	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicit in the document, but has synergy with Strategic Axis 3.1 - Agriculture and Forests (3.1.3: Low carbon agriculture and adaptation in the productive sector), particularly when it comes to actions in the area of agriculture that should focus on promoting emission-mitigating agricultural technologies in already anthropized areas that encourage the adoption of conservationist systems and practices and reduce the vulnerability of agricultural systems to climate change.	
	Feasibility of adoption under the institutional framework	4
	The country has a legal framework for technology implementation, but adaptations are required for its expansion.	

continues

continuation

MACRO-CRITERIA	INDICATOR	SCORE
GENETIC IMPROVEMENT IN BEEF CATTLE (AFOLU/LIVESTOCK)		
Technological	Technology Readiness	2
	Genetic engineering is already a technology studied and applied globally, such as the selection and crossing of animals of the herd with characteristics of interest. However, there are critical gaps in scientific knowledge about genetic improvement in food efficiency and, therefore, advances in scientific knowledge about this technology are needed.	
	Mitigation potential	4
	The technology has relevant mitigation potential due to the expected reduction in methane emissions in animals with higher feed efficiency (10).	
	Mitigation cost	3
	The cost varies within an extensive range given the technological options included in this measure. In this sense, the median was chosen according to the normalization of costs, which implies neutrality in the indicator. In general, the costs of genetic selection may vary according to individual consumption measurement and genetic improvement methods (female bull exposure, artificial insemination, fixed-time artificial insemination, for example).	
	Vulnerability to climate change	4
	Possibility of selecting individuals more adapted to climate change.	
Physical	Health and pollution reduction	4
	Animal genetic improvement can reduce GHG emissions, thus bringing health benefits.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	4
	The technology increases beef production.	
	Impact on biodiversity conservation	2
	The selection of traits can increase herd homozygosity.	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral on this criterion.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive Advantages of Brazil	5
	Brazil is one of the largest beef producers and the implementation of technology can further enhance the country's competitive advantages.	

continues

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MACRO-CRITERIA	INDICATOR	SCORE
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not made explicit in Encti, but has synergy and may be appropriate to the strategic theme "Food", in particular the strategy associated with "Strengthening research in frontier knowledge areas (biotechnology, bioinformatics, nanotechnology, modeling, simulation and automation") aiming at increasing productivity, adapting to climate change and agricultural defense ".	
	Synergies with national climate policies	4
	The technology is not explicit in national climate policy, but has synergy with the opportunities for mitigation of the agricultural sector of the National Climate Change Plan, particularly the intensification of cattle ranching, and with the ABC Plan, regarding adaptation to climate change. "Encourage and support programs for the conservation and sustainable use of genetic resources and plant and animal breeding, with an emphasis on their adaptation to the prevailing biotic and abiotic factors in foreseeable scenarios of average warming equivalent to 2 ° C".	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	The technology is not explicit in the document, but has synergy with Strategic Axis 3.1 - Agriculture and Forests (3.1.3: Low carbon agriculture and adaptation in the productive sector), particularly when it comes to actions in the area of agriculture that should focus on promoting emission-mitigating agricultural technologies in already anthropized areas that encourage the adoption of conservationist systems and practices and reduce the vulnerability of agricultural systems to climate change.	
	Feasibility of adoption under the institutional framework	4
	The country has a legal framework for technology implementation, but adaptations are required for its expansion.	

continues

continuation

MACRO-CRITERIA	INDICATOR	SCORE
NUTRITIONAL SUPPLEMENTATION (AFOLU/LIVESTOCK)		
Technological	Technology Readiness	4
	Nutritional supplementation is already a globally accepted practice, but further advances in scientific knowledge and technological development of new products such as precision nutrition, nutrient supplementation, and inhibition of rumen methane production are needed.	
	Mitigation potential	4
	Nutritional supplementation reduces the need to open new grazing areas, enables increased animal productivity, and reduced slaughter age (8), factors that contribute to reducing GHG emissions.	
	Mitigation cost	3
	The cost varies within an extensive range given the technological options included in this measure. In this sense, the median was chosen according to the normalization of costs, which implies neutrality in the indicator. In general, costs vary between type of supplementation and objective: mineral salt, roughage/concentrate and specific supplements (precision nutrition, nutrient supplementation, inhibition of rumen methane production).	
	Vulnerability to climate change	2
	It is possible to reduce the availability of inputs for the production of roughage and concentrate due to extreme weather phenomena.	
Physical	Health and pollution reduction	4
	The application of technology reduces slaughter time and reduces methane emission.	
	Impact on water availability	3
	The technology is considered neutral on this criterion.	
	Impact on food production	4
	It leads to increased food production.	
	Impact on biodiversity conservation	3
	The technology is considered neutral on this criterion.	
Socio-economic	Impact on energy availability	3
	The technology is considered neutral on this criterion.	
	Jobs and income generation	3
	The technology is considered neutral on this criterion.	
	Competitive Advantages of Brazil	5
	Brazil is a relevant meat producer and the implementation of technology can further enhance the country's competitive advantages.	
Institutional	Synergy with the country's National Strategy for ST&I	4
	The technology is not made explicit in Encti, but has synergy and may be appropriate to the strategic theme "Food", in particular the strategy associated with "Strengthening research in frontier knowledge areas (biotechnology, bioinformatics, nanotechnology, modeling, simulation and automation") aiming at increasing productivity, adapting to climate change and agricultural defense ".	
	Synergies with national climate policies	4
	The technology has synergy with mitigation opportunities in the agricultural sector reported in the National Plan on Climate Change (NPCC) (9), in particular the intensification of cattle ranching.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	2
	The technology is not explicit in the document, but has synergy with Strategic Axis 3.1 - Agriculture and Forests (3.1.3: Low carbon agriculture and adaptation in the productive sector)	
	Institutional framework	4
	There is a favorable institutional framework for the implementation of technology, but there are barriers that may hinder its expansion, such as the difficulty of access to rural credit, especially small and medium producers, as well as the lack of rural technical assistance.	

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MACRO-CRITERIA	INDICATOR	SCORE
PRECISION FORESTRY AND SILVICULTURE (AFOLU/OTHER LAND USES)		
Technological	Technology Readiness	2
	Geotechnologies (satellites, aerial photography, LiDAR, etc.) are commercially available. However, significant advances are needed in the design and implementation of efficient systems for collecting, analyzing, and monitoring spatial data.	
	Mitigation potential	5
	Relevant mitigation potential due to the expected increase in forest productivity and fertilizer application reductions (indirect emissions).	
	Mitigation cost	5
	The technology has a significantly negative marginal cost of rebate.	
	Vulnerability to climate change	4
	Efficient systems capable of integrating site-specific productivity maps and climate data allow us to internalize climate risks.	
Physical	Health and pollution reduction	4
	Technology reduces the application of agricultural inputs (fertilizers, concealers, and pesticides, etc.).	
	Impact on water availability	4
	Monitoring the qualitative and quantitative parameters of water and water resources implicit to technology can result in optimal water use.	
	Impact on food production	3
	The technology is neutral on this criterion.	
	Impact on biodiversity conservation	1
	Significantly reduces biodiversity due to the application of precision forestry in clonal monocultures of eucalyptus and pine.	
Socio-economic	Impact on energy availability	4
	Gains in forest productivity may allow a higher supply of wood products for energy purposes (i.e. wood chips).	
	Jobs and income generation	2
	Precision forestry implies process automation, thus leading to less use of the workforce.	
	Competitive Advantages of Brazil	5
	Brazil is a reference in the market (domestic and foreign) of forest products due to its edaphoclimatic characteristics and technologies. Therefore, the impacts arising from obtaining competitive advantages would be very relevant.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	The technology has excellent synergy with the strengthening of modeling, simulation, and automation research, aiming at increasing productivity, climate change adaptation and agricultural defense, which are covered by Encti.	
	Synergies with national climate policies	5
	The NDC explicitly foresees the expansion of planted forests, which makes the technology very relevant due to productivity and scale gains.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	4
	Strong adherence to "Strategic Axis 3.1 - Agriculture and Forests", which deals with the "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	5
	Brazil has reference institutions such as Embrapa Forests and it also has a National Plan of Planted Forests.	

continues

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MACRO-CRITERIA	INDICATOR	SCORE
MIXED PLANTING SILVICULTURE WITH EXOTIC AND NATIVE SPECIES (AFOLU/OTHER LAND USES)		
Technological	Technology Readiness	1
	Current mixed planting techniques are mostly geared towards exotic monocultures. A significant advance in knowledge is needed for native species, including genetic improvement and mixed forestry models.	
	Mitigation potential	5
	Relevant mitigation potential due to the expected increase in forest productivity and reduced fertilizer. Moreover, increased soil carbon stocks are expected compared to traditional plantings.	
	Mitigation cost	4
	The technology has a slightly negative marginal cost of rebate.	
	Vulnerability to climate change	4
	Mixed plantings favor increased biodiversity and climate resilience over monocultures of exotic species.	
Physical	Health and pollution reduction	4
	Well managed mixed plantings can reduce fertilizer and pesticide application compared to monocultures of exotic species.	
	Impact on water availability	4
	When used for restoration of degraded areas, they can contribute to the recovery of ecosystem services, including water availability.	
	Impact on food production	4
	There is the possibility of combining timber and non-timber species for food production.	
	Impact on biodiversity conservation	4
	Mixed plantations favor increased biodiversity and climate resilience compared to monocultures of exotic species. There is also a potential for inclusion of endangered native species.	
Socio-economic	Impact on energy availability	3
	Wood production in mixed plantations is expected to focus on nobler woods and other non-energy uses. Therefore, technology is considered neutral in this indicator.	
	Jobs and income generation	4
	Mixed planting tends to have a positive impact on job creation, especially by hiring local labor. A positive socio-economic agenda related to forest restoration is also expected.	
	Competitive Advantages of Brazil	5
	The country is in a privileged position for having the largest floristic biodiversity in the world (native species) and presenting the highest rates of forest products from exotic species (pine and eucalyptus). Therefore, the impacts arising from obtaining competitive advantages would be very relevant.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	High synergy with Encti in biomes and bioeconomic that foresee investments in forest restoration and biomass generating technologies, respectively (11)	
	Synergies with national climate policies	5
	NDC explicitly provides for the expansion of planted forests for multiple uses, and this flexibility the central point of technology	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology has strategic synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	5
	Brazil has reference institutions such as Embrapa Forests and it also has a National Plan of Planted Forests.	

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MACRO-CRITERIA	INDICATOR	SCORE
GENETIC IMPROVEMENT OF FORESTS (AFOLU/OTHER LAND USES)		
Technological	Technology Readiness	4
	The current genetic improvement is mostly aimed on exotic monocultures (Eucalyptus and Pinus), and it is necessary to advance scientific and technological knowledge related to native species. Currently, there is only concept validation in the laboratory of the genetic improvement of native species.	
	Mitigation potential	4
	Relevant mitigation potential due to an expected increase in forest productivity, reduction of fertilizers and restoration of ecosystem services.	
	Mitigation cost	5
	The technology has a significantly negative marginal cost of rebate.	
	Vulnerability to climate change	2
	Genetic improvement may contribute to the selection of resilient varieties. However, efforts are currently directed towards the production of exotic clones, which negatively impacts climate resilience.	
Physical	Health and pollution reduction	4
	Relevant potential to foster the establishment of native and mixed-species plantations for restoration of ecosystem services, including pollution reduction and health benefits.	
	Impact on water availability	4
	Relevant potential to foster the establishment of mixed and native species plantations for the restoration of ecosystem services, including positive impacts on water availability.	
	Impact on food production	4
	Genetic improvement can be used for establishing mixed silvicultural arrangements for timber production and food (i.e. inclusion of fruit species).	
	Impact on biodiversity conservation	2
	Genetic improvement currently focuses on producing clones for commercial crops rather than increasing the use of diverse systems.	
Socio-economic	Impact on energy availability	3
	Logging is expected to focus on nobler woods and other non-energy uses. Therefore, technology is considered neutral in this indicator.	
	Jobs and income generation	3
	Technology is considered neutral in this indicator.	
	Competitive Advantages of Brazil	5
	The country is in a privileged position for being an international reference in the area of genetic improvement of timber species.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	High synergy with the Science, Technology, and Innovation in Bioeconomics that foresees investments in technologies of biomass generators, respectively (11)	
	Synergies with national climate policies	5
	The NDC explicitly foresees the expansion of multi-purpose planted forests, which makes technology key to improving silvicultural arrangements and increasing productivity.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology has strategic synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	5
	Brazil has reference institutions such as Embrapa Forests. It also has a National Plan of Planted Forests.	

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MACRO-CRITERIA	INDICATOR	SCORE
SILVICULTURE WITH NATIVE SPECIES FOR RESTORATION (AFOLU/OTHER LAND USES)		
Technological	Technology Readiness	1
	Today's forestry technologies are mostly geared towards exotic monocultures (traditional forestry). It is necessary to significantly advance scientific and technological knowledge for native species aiming at balancing timber production and ecological restoration.	
	Mitigation potential	5
	Relevant mitigation potential due to increased carbon stocks and restoration of ecosystem services. Increases in soil carbon stocks are expected compared to traditional plantations of exotic species.	
	Mitigation cost	5
	The technology has a significantly negative marginal cost of rebate.	
	Vulnerability to climate change	5
	Native plantings favor increased biodiversity and climate resilience compared to monocultures of exotic species.	
Physical	Health and pollution reduction	5
	Native plantings have great potential for the restoration of ecosystem services, including pollution reduction and health benefits.	
	Impact on water availability	5
	Native plantings have great potential for the restoration of ecosystem services, including positive impacts on water availability.	
	Impact on food production	4
	Native plantings have the potential for restoration of ecosystem services and food production (i.e., the inclusion of fruit species).	
	Impact on biodiversity conservation	5
	Native plantings have great potential for the restoration of ecosystem services and protection of biodiversity (i.e. including endangered native species).	
Socio-economic	Impact on energy availability	3
	Timber production is expected to focus on lighter woods and other non-energy uses. Therefore, technology is considered neutral in this indicator.	
	Jobs and income generation	5
	Native plantings have great potential for job and income generation, especially by hiring local labor.	
	Competitive Advantages of Brazil	5
	The country is in a privileged position for having the largest floristic biodiversity in the world (native species) and well-developed silvicultural technologies for exotic species.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	High synergy with Science, Technology and Action Plans Bioeconomics innovation that foresees investments in forest restoration and biomass generating technologies, respectively (11)	
	Synergies with national climate policies	5
	The NDC explicitly foresees the expansion of multi-purpose planted forests, which makes technology key to improving silvicultural arrangements and increasing productivity.	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology has relevant synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	4
	Brazil has reference institutions such as Embrapa Forests. It also has a National Plan of Planted Forests.	

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<table>
<tr><th>MACRO-CRITERIA</th><th>INDICATOR</th><th>SCORE</th></tr>
<tr><td colspan="3">CONSERVATION AND GENETIC IMPROVEMENT OF NATIVE SPECIES (AFOLU/OTHER LAND USES)</td></tr>
<tr><td rowspan="8">Technological</td><td>Technology Readiness</td><td>1</td></tr>
<tr><td colspan="2">The current paradigm is for exotic monocultures. Significant advances in knowledge of native species ecology, population genetics, flowering and fruiting phenology, and forest production are needed.</td></tr>
<tr><td>Mitigation potential</td><td>4</td></tr>
<tr><td colspan="2">Relevant mitigation potential due to the expected increase in forest productivity, fertilizer reduction, and restoration of ecosystem services through native species plantations.</td></tr>
<tr><td>Mitigation cost</td><td>4</td></tr>
<tr><td colspan="2">Expansion of planted forests has a negative marginal abatement cost and can drive investments to develop native breeding.</td></tr>
<tr><td>Vulnerability to climate change</td><td>5</td></tr>
<tr><td colspan="2">Great potential to foster native forestry and mixed planting by expanding the range of species and biodiversity forestry arrangements.</td></tr>
<tr><td rowspan="8">Physical</td><td>Health and pollution reduction</td><td>4</td></tr>
<tr><td colspan="2">Relevant potential to foster the establishment of native species plantations for the restoration of ecosystem services, including pollution reduction and health benefits.</td></tr>
<tr><td>Impact on water availability</td><td>4</td></tr>
<tr><td colspan="2">Relevant potential to foster the establishment of native species plantations for the restoration of ecosystem services, including positive impacts on water availability (especially in the medium and long term).</td></tr>
<tr><td>Impact on food production</td><td>4</td></tr>
<tr><td colspan="2">Conservation and genetic improvement can be used for the purpose of establishing mixed silvicultural arrangements aiming at timber production and food (example: inclusion of fruit species).</td></tr>
<tr><td>Impact on biodiversity conservation</td><td>5</td></tr>
<tr><td colspan="2">Genetic improvement has great potential to enable the establishment of mixed silvicultural arrangements based on native species and biodiversity protection.</td></tr>
<tr><td rowspan="6">Socio-economic</td><td>Impact on energy availability</td><td>3</td></tr>
<tr><td colspan="2">Logging is expected to focus on nobler woods and other non-energy uses. Therefore, technology is considered neutral in this indicator.</td></tr>
<tr><td>Jobs and income generation</td><td>3</td></tr>
<tr><td colspan="2">It demands skilled labor but tends to optimize processes to the detriment of human operational work. Therefore, technology is considered neutral in this indicator.</td></tr>
<tr><td>Competitive Advantages of Brazil</td><td>5</td></tr>
<tr><td colspan="2">The country is in a privileged position for being an international reference in the area of genetic improvement of timber species.</td></tr>
<tr><td rowspan="8">Institutional</td><td>Synergy with the country's National Strategy for ST&I</td><td>5</td></tr>
<tr><td colspan="2">High synergy with the Science, Technology and
Innovation in biomes providing for investments in forest restoration technologies (11)</td></tr>
<tr><td>Synergies with national climate policies</td><td>4</td></tr>
<tr><td colspan="2">NDC aims to restore and reforest 12 million hectares of forests for multiple uses, which strategically positions the technology to harness the potential of native species in Brazil.</td></tr>
<tr><td>Synergies with Brazil's Country Program for the Green Climate Fund (GCF)</td><td>5</td></tr>
<tr><td colspan="2">The technology has great synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".</td></tr>
<tr><td>Feasibility of adoption under the institutional framework</td><td>4</td></tr>
<tr><td colspan="2">Brazil has reference institutions such as Embrapa Forests. It also has a National Plan of Planted Forests.</td></tr>
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MACRO-CRITERIA	INDICATOR	SCORE
SATELLITE MONITORING (AFOLU/CROSS-SECTORAL)		
Technological	Technology Readiness	3
	Brazil already has robust systems for detecting deforestation in the Amazon and Savannah (Cerrado). However, further progress is needed in monitoring deforestation in other biomes, and in monitoring native vegetation restoration based on high-resolution images and new land use and land cover classification techniques.	
	Mitigation potential	5
	Relevant mitigation potential due to greater control of deforestation and restoration incentives.	
	Mitigation cost	4
	The cost of developing these systems is relatively low, given the coverage area on a national scale.	
	Vulnerability to climate change	3
	Technology is considered neutral in this criterion.	
Physical	Health and pollution reduction	4
	It contributes to controlling deforestation and increasing restoration efforts with relevant potential for reducing pollution and generating health benefits.	
	Impact on water availability	5
	It contributes to controlling deforestation and increasing restoration efforts with a significant impact on water availability.	
	Impact on food production	4
	It contributes to controlling deforestation and increasing restoration efforts with a significant impact on food production through the protection of ecosystem services such as pollination and maintenance of the water regime for crops.	
	Impact on biodiversity conservation	5
	Greater control of deforestation has a significant impact on biodiversity protection.	
Socio-economic	Impact on energy availability	4
	It contributes to controlling deforestation and increasing restoration efforts by having a significant impact on electricity availability through higher protection of water resources used by hydroelectric plants.	
	Jobs and income generation	2
	Large-scale monitoring systems tend to favor highly skilled labor and automated processes over human operational work.	
	Competitive Advantages of Brazil	4
	Investments in satellite monitoring will contribute to maintaining Brazil's leadership in this technology sector, as well as enabling better territorial planning.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	The development of applications that exploit technologies and spatial data in Earth observation areas is covered by the National Science, Technology and Innovation Strategy (2016-2022) (2)	
	Synergies with national climate policies	5
	Expansion of deforestation monitoring systems nationwide and the establishment of a high-resolution restoration monitoring system are required to achieve zero illegal deforestation and restore 12 million hectares of NDC-predicted forest by 2030 (3)	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology has great synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	5
	Investment in expanding and improving monitoring systems is in line with the objectives of the National Climate Change Policy, Forest Code, and federal and state deforestation prevention and control plans.	

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MACRO-CRITERIA	INDICATOR	SCORE
VALIDATION SYSTEMS FOR THE RURAL ENVIRONMENTAL REGISTRY (AFOLU/CROSS-SECTORAL)		
Technological	Technology Readiness	2
	Significant progress is required in the design and use of computer systems for big data processing, including analysis of land, hydrological and land use, and land cover data.	
	Mitigation potential	4
	A robust and agile system for validating and publicizing Rural Environmental Registry data has the potential to contribute to the control of deforestation and forest restoration.	
	Mitigation cost	4
	The cost of developing these systems is relatively low, given their importance for the implementation of the Forest Code.	
	Vulnerability to climate change	3
	Technology is considered neutral in this criterion.	
Physical	Health and pollution reduction	4
	Relevant potential for deforestation control and incentive to low carbon agricultural practices, which favors the reduction of pollution and generates health benefits.	
	Impact on water availability	4
	Relevant potential for deforestation control and incentive to low carbon agricultural practices, which favors the availability of water.	
	Impact on food production	4
	Relevant potential to control deforestation and encourage sustainable practices, which favors food production.	
	Impact on biodiversity conservation	4
	Relevant potential to control deforestation and encourage low carbon agricultural practices, which favors the protection of biodiversity.	
Socio-economic	Impact on energy availability	4
	The technology has relevant potential to control deforestation and encourage low carbon practices, which favors the protection of water bodies.	
	Jobs and income generation	3
	Technology is considered neutral in this criterion.	
	Competitive Advantages of Brazil	4
	Brazil has monitoring systems that can be upgraded and internationally recognized remote sensing research institutions.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	The development of applications that exploit technologies and spatial data in Earth observation areas is covered by the National Science, Technology and Innovation Strategy (2016-2022) (2)	
	Synergies with national climate policies	5
	CAR validation is required to implement the Forest Code, thereby achieving zero illegal deforestation and restoring 12 million hectares of forests by 2030 predicted by the NDC (3)	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology has great synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	4
	The validation of the CAR is one of the necessary steps for the implementation of the Forest Code by the state environmental agencies in articulation with the federal government.	

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MACRO-CRITERIA	INDICATOR	SCORE
CERTIFICATION SYSTEMS FOR CHAINS THAT ARE DEFORESTATION-FREE (AFOLU/CROSS-SECTORAL)		
Technological	Technology Readiness	3
	The country has efficient certification systems for some products such as wood. However, it needs to move towards certification schemes for other more complex agricultural products (i.e., beef).	
	Mitigation potential	5
	Certification of production chains with a relevant impact on deforestation and forest degradation have great mitigation potential due to pressure from national and international consumers.	
	Mitigation cost	4
	The cost of developing these systems is relatively low, given their importance for reducing deforestation and GHG emissions.	
	Vulnerability to climate change	3
	Technology is considered neutral in this criterion.	
Physical	Health and pollution reduction	4
	Certification of supply chains puts pressure on producers to pursue and implement practices with lower environmental impact, which bring relevant synergy in terms of pollution reduction and health improvement.	
	Impact on water availability	4
	Supply chain certification puts pressure on producers to pursue and implement practices with less impact on water resources.	
	Impact on food production	4
	The certification of production chains puts pressure on producers to pursue and implement agricultural intensification practices with higher meat production.	
	Impact on biodiversity conservation	4
	Certification has relevant impact on deforestation and forest degradation has the potential to control the loss of ecosystem services	
Socio-economic	Impact on energy availability	3
	Technology is considered neutral on this criterion.	
	Jobs and income generation	4
	Supply chain certification has relevant potential for hiring and training local labor.	
	Competitive Advantages of Brazil	4
	Brazil has relevant experience in the certification of wood and other forest products.	
Institutional	Synergy with the country's National Strategy for ST&I	5
	The development of applications that exploit technologies and spatial data in Earth observation areas is covered by the National Science, Technology and Innovation Strategy (2016-2022) (2)	
	Synergies with national climate policies	5
	Certification of supply chains as deforestation-free contributes to achieving the NDC goal of illegal deforestation by 2030 (3)	
	Synergies with Brazil's Country Program for the Green Climate Fund (GCF)	5
	The technology has great synergy with Strategic Axis I - Agriculture and Forests, which deals with "Sustainable Management of Forest Assets, Forest Economy and Market Access".	
	Feasibility of adoption under the institutional framework	2
	The development of a certification system is in line with the objectives of the National Climate Change Policy and Forest Code, but currently the legislation is unclear about the possibility of making agriculturally traceability data available for phytosanitary purposes also for environmental purposes.	

Source: Author's elaboration from the list of references available in this link.

APPENDIX IV – BARRIERS TO THE DEVELOPMENT AND/OR DIFFUSION OF THE SELECTED TECHNOLOGIES

SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
ADVANCED FLUIDIZED BED	
Industrial (Cement)	• Lack of local technology content; • High cost of capital; • Low level of technological maturity; • Conservatism in the construction sector; • Ignorance of the benefits of technology.
GEOPOLYMER CEMENT	
Industrial (Cement)	• Lack of local technology content; • High cost of capital; • Low level of technological maturity; • Ignorance of the benefits of technology; • Conservatism in the construction sector; • Lack of specifications for the use of the material in the production of cement.
INNOVATIVE MATERIALS FOR CEMENT	
Industrial (Cement)	• Low reactivity of additions; • Lack of specifications for concrete; • Ignorance of the availability of supplementary cementitious materials; • Low qualification level of small contractors; • Conservatism in the construction sector.
SOLAR HYBRID PLANTS	
Industrial (Cement)	• High cost of capital; • Low level of technological maturity; • Ignorance of the benefits of the technology; • Conservatism in the construction sector; • Lack of experience in using the technology as an energy source for calcination furnaces.
CO_2 CAPTURE	
Industrial (Cement)	• Uncertainty about the application of the technology on a large scale; • High cost of capital and operation and maintenance of capture technology; • Competition with other investments; • Lack of local technology content; • Conservatism in the construction sector; • Lack of regulatory framework for the transport of captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
OXYGEN ENRICHMENT SYSTEMS	
Industrial (Cement)	• High cost of capital and operation and maintenance of capture technology; • Competition with other investments; • Lack of local technology content; • Ignorance of the benefits of the technology; • Conservatism in the construction sector; • Applicability of equipment, considering the configuration of industrial plants.
CHEMICAL LOOPING	
Industrial (Cement)	• High cost of capital and operation and maintenance of capture technology; • Competition with other investments; • Lack of local technology content; • Ignorance of the benefits of the technology; • Conservatism in the construction sector; • Applicability of equipment, considering the configuration of industrial plants.
USE OF MEMBRANE SEPARATION	
Industrial (Chemical)	• Need to import components due to the lack of local technology content; • Installation restrictions due to plant layout; • Low technology readiness level; • Lack of capital to fund research and development; • Risk of over- or under-dimensioning new technologies; • Lack of confidence in the economic feasibility of the technology among investors.
CATALYTIC CRACKING OF NAPHTHA	
Industrial (Chemical)	• Need to import components due to the lack of local technology content; • Ignorance of the benefits of the technology, due to its low penetration in the global chemicals sector; • Installation restrictions due to plant layout; • Lack of investor confidence in the economic feasibility of the technology; • Lack of technology licensors in Brazil.
USE OF BIOMASS FOR OLEFIN PRODUCTION	
Industrial (Chemical)	• Installation restrictions due to plant layout; • Raw material not available on the required scale; • Energy penalty of cracking technology; • Competition with the use of ethanol in the transport sector, in the case of using ethanol catalytic dehydration; • Low technology penetration in Brazil; • Lack of mechanisms for evaluating the environmental advantages of the technology to make it a viable competitor with the petrochemical industry.
USE OF H_2 FROM RENEWABLE SOURCES FOR THE PRODUCTION OF AMMONIA AND METHANOL	
Industrial (Chemical)	• Installation restrictions due to plant layout; • Low penetration of the use of the technology in Brazil; • Lack of equipment supply chain for water electrolysis; • Energy penalty and higher production costs compared to the conventional technologies (steam reforming of natural gas); • Ignorance of the benefits of the technology.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
CARBON CAPTURE IN AMMONIA PRODUCTION	
Industrial (Chemical)	• Uncertainty about the application of the technology on a large scale; • High cost of capital and operation and maintenance of capture technology; • Lack of local technology content; • Competition with other investments; • Lack of regulatory framework for the transport of captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs.
STEAM REFORMING OF COKE OVEN GAS	
Industrial (Iron and Steel)	• Lack of local technology content; • High cost of capital; • Competition with other investments; • Low level of technological maturity; • Ignorance of the benefits of the technology, due to the lack of application on a national level.
RECOVERY OF RESIDUAL HEAT FROM ELECTRIC ARC FURNACES USING THE ORGANIC RANKINE CYCLE	
Industrial (Iron and Steel)	• Lack of local technology content; • Uncertainty about the application of the technology on a large scale; • Competition with other investments; • High cost of capital; • Ignorance of the benefits of the technology, due to the lack of application on a national level.
APPLICATION OF THE SIDERWIN PROCESS	
Industrial (Iron and Steel)	• Competition with other investments; • Uncertainty about the application of the technology on a large scale; • Lack of local technology content; • Low level of technological maturity; • Ignorance of the benefits of technology, due to the lack of application at an experimental level in the country.
APPLICATION OF DRYING, PYROLYSIS AND COOLING (DPC) TECHNOLOGY IN CHARCOAL PRODUCTION	
Industrial (Iron and Steel)	• Competition with other investments; • Uncertainty about the application of the technology on a large scale; • Lack of local technology content; • Ignorance of the benefits of the technology, due to the lack of application at an experimental level in the country; • Lack of knowledge among investors about the environmental damage from traditional ovens and the economic feasibility of the technology.
APPLICATION OF ONDATEC TECHNOLOGY IN CHARCOAL PRODUCTION	
Industrial (Iron and Steel)	• Competition with other investments; • Uncertainty about the application of the technology on a large scale; • Lack of local technology content; • Ignorance of the benefits of the technology, due to the lack of application at an experimental level in the country; • Lack of knowledge among investors about the environmental damage from traditional ovens and the economic feasibility of the technology.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
BLAST FURNACE GAS COLLECTION AND REFORMING WITH THE IGAR PROCESS	
Industrial (Iron and Steel)	• High cost of capital; • Competition with other investments; • Low level of technological maturity; • Ignorance of the benefits of the technology, due to the lack of experimental application worldwide.
APPLICATION OF THE HISARNA PROCESS FOR FUSION REDUCTION	
Industrial (Iron and Steel)	• Competition with other investments; • Uncertainty about the application of the technology on a large scale; • Lack of local technology content; • Low level of technological maturity; • Ignorance of the benefits of the technology, due to the lack of application at an experimental level in the country.
INDUSTRY 4.0	
Industrial (Cross-sectoral)	• Limited broadband infrastructure and mobile network; • Lack of digital integration of companies along production chains; • Concept not widespread; • Lack of local technology content; • Insufficient workforce; • Uncertain return on investment; • Outdated regulations for cyber security and interoperability standards.
USE OF RENEWABLE ENERGY IN INDUSTRIAL PROCESSES	
Industrial (Cross-sectoral)	• Financial uncertainty associated with the intermittency of renewable energy sources; • Need for large-scale supply and difficulty storing energy generated by renewable sources; • Lack of infrastructure to connect to the network.
TRANSPORT OF CO_2	
Industrial (Cross-sectoral)	• Uncertainty about the application of carbon capture technology on a large scale; • High cost of capital for the installation of carbon pipelines; • Lack of regulatory framework for the transport of captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Lack of mechanisms to promote the mitigation of GHG emissions.
STORAGE OF CO_2	
Industrial (Cross-sectoral)	• Uncertainty about the application of carbon capture technology on a large scale; • High cost of capital for the installation of carbon pipelines; • Lack of regulatory framework for CO_2 storage; • Lack of mechanisms to promote the mitigation of GHG emissions.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
IMPLEMENTATION OF FLARE PILOTS	
Energy (Oil and gas E&P)	• Lack of emission limits for platforms; • Safety and reliability of flare pilot ignition systems; • Ignorance of the costs and advantages of the technology.
INSTALLATION OF STEAM RECOVERY UNITS IN STORAGE TANKS	
Energy (Oil and gas E&P)	• Lock-in associated with the lack of space on platforms; • Lack of emission limits for platforms; • Ignorance of the costs and advantages of the technology.
GAS-TO-LIQUIDS (GTL)	
Energy (Oil and gas E&P)	• Lack of economic viability; • Competition with other investments; • Lack of emission limits for platforms and equipment; • Ignorance of the costs and advantages of the application; • Need for the development of catalytic nanomaterials resistant to rapid carbon accumulation (coke).
CO_2 CAPTURE IN THE PRODUCTION OF OIL AND NATURAL GAS	
Energy (Oil and gas E&P)	• Uncertainty about the application of the technology on a large scale • High cost of capital and operation and maintenance of capture technology; • Lack of local technology content; • Competition with other investments; • Lack of regulatory framework for the transport of captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs.
CO_2 CAPTURE IN FLUID CATALYTIC CRACKING UNITS	
Energy (Oil refining)	• Uncertainty about the application of the technology on a large scale • High cost of capital and operation and maintenance of capture technology; • Lack of local technology content; • Competition with other investments; • Lack of regulatory framework for the transport of captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs. • Ability of furnaces and other equipment to withstand the high temperatures from burning concentrated oxygen.
CO_2 CAPTURE IN HYDROGEN GENERATION UNITS	
Energy (Oil refining)	• Uncertainty about the application of the technology on a large scale • High cost of capital and operation and maintenance of capture technology; • Competition with other investments; • Lack of local technology content; • Lack of regulatory framework for the transport of captured CO_2; • Absence of carbon pipelines to transport captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
HYDROKINETIC TURBINES	
Energy (Electric)	• Lack of economic viability; • Competition with other investments; • Ignorance of the costs and advantages of the technology; • Lack of local technology content; • Lack of emission limits for the electricity sector; • Technological lock-in and installation restrictions due to the layout of hydroelectric plants; • Limits on installation due to river flow speed.
REVERSIBLE HYDROELECTRIC PLANTS	
Energy (Electric)	• Lack of economic viability; • Competition with other investments; • Economic disincentive due to the HPP remuneration for the physical guarantee; • Increase in generation costs due to the duplicity of operations (turbine power generation from the water in the elevated reservoir and accumulation of energy); • Ignorance of the costs and advantages of the technology; • Lack of local technology content; • Economic, social and environmental impacts from the construction of a water reservoir; • No distinction in remuneration for HPPs that produce on-site; • Lack of emission limits for the electricity sector; • Technological lock-in and installation restrictions due to the layout of hydroelectric plants; • Limits on installation due to river flow speed.
REPOWERING OF HYDROELECTRIC PLANTS	
Energy (Electric)	• Expansion of power increases sectoral Amount of Transmission System Use charges (*Montante de Utilização do Sistema de Transmissão - MUST*); • Competition with other investments; • Lack of economic viability; • Ignorance of the costs and advantages of the technology; • Lack of emission limits for the electricity sector; • Plants are remunerated by the physical guarantee, which does not necessarily increase with repowering; • Technological lock-in and installation restrictions due to the layout of hydroelectric plants.
OFFSHORE WIND POWER	
Energy (Electric)	• Lack of local technology content; • Ignorance of the benefits of the technology, in view of the lack of ventures operating nationally; • High cost of capital, operation and maintenance; • Lack of infrastructure for energy transmission; • Lack of regulatory framework for contracting energy and operating the system; • Lack of economic viability; • Lack of labor for installation and maintenance of offshore wind towers.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
INTEGRATED COMBINED CYCLE WITH BIOMASS GASIFICATION IN THERMOELECTRIC PLANTS	
Energy (Electric)	• Lack of local technology content; • Ignorance of the benefits of the technology, given the lack of enterprises operating on a commercial scale; • High cost of capital, operation and maintenance; • Reduction in the performance of the gas turbine due to the need for adaptations for synthesis gas processing; • Lack of economic viability; • Technological lock-in and installation restrictions due to the layout of thermoelectric plants; • Difficulty to clean the synthesis gas generated.
CONCENTRATED SOLAR POWER (CSP)	
Energy (Electric)	• Lack of transmission networks in areas with high potential for using the solar resource; • Lack of local specific component suppliers and high cost of importing components; • High investment costs and high cost of generated energy; • In the case of hybridization via gasification, the process still has a low level of technological maturity; • Lack of competitiveness compared to conventional electricity generation; • Lack of labor to install and operate the plants._
FLOATING SOLAR POWER PLANTS	
Energy (Electric)	• Lack of an inventory of the potential of the source; • Ignorance of the potential environmental impacts of projects; • Difficulty in anchoring in large reservoirs and/or with big variations in water levels; • Low level of technological maturity of floating inverters in large reservoirs; • High capital costs; • Ignorance of the technology and benefits.
CO_2 CAPTURE IN NATURAL GAS THERMOELECTRIC PLANTS	
Energy (Electric)	• Uncertainty about the application of the technology on a large scale • High cost of capital and operation and maintenance of capture technology; • Competition with other investments; • Lack of local technology content; • Lack of regulatory framework for the transport of captured CO_2; • Lack of carbon pipelines to transport captured CO_2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs.
CO_2 CAPTURE IN COAL-FIRED THERMOELECTRIC POWER PLANTS	
Energy (Electric)	• Uncertainty about the application of the technology on a large scale; • High cost of capital and operation and maintenance of capture technology; • Competition with other investments; • Lack of local technology content; • Lack of regulatory framework for the transport of captured CO_2; • Lack of carbon pipelines to transport captured CO2; • Applicability of equipment, considering the configuration of industrial plants; • Significant energy penalty, implying high associated energy costs.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
SECOND GENERATION ETHANOL	
Energy (Biofuels)	• Risk of corrosion of engine components, due to the use of strong acids (acid hydrolysis technology); • Energy penalty in view of the need to recover the acid used; • Generation of undesirable reaction by-products, which can inhibit yeast metabolism in the fermentation stage; • Low level of maturity in the development of enzymes and high cost of production (enzymatic hydrolysis technology); • Lack of investment in research and development; • Technology at the demonstration stage and lacking competitiveness in relation to ethanol produced from sugarcane and corn.
GREEN DIESEL	
Energy (Biofuels)	• Low technology readiness level, regardless of the production technology considered; • Lack of investment in research and development; • High viscosity, acidity and high level of oxygenated compounds, which can corrode equipment (pyrolysis technology); • Risk of poisoning the catalysts in the synthesis stage (gasification technology); • Lack of competitiveness compared to mineral diesel.
BIOJET (AVIATION BIOFUEL)	
Energy (Biofuels)	• Low technology readiness level, regardless of the production technology considered; • Lack of investment in research and development; • Lack of competitiveness in relation to aviation kerosene; • High viscosity, acidity and high level of oxygenated compounds, which can corrode equipment (pyrolysis technology); • Risk of poisoning the catalysts in the synthesis stage (gasification technology); • Technological lock-in related to difficulties in implementing the alcohol-to-jet (TKA) technology in ethanol distilleries; • Competition for ethanol with the automobile sector.
BIOBUNKER FOR MARITIME TRANSPORT	
Energy (Biofuels)	• Low technology readiness level, regardless of the production technology considered; • Lack of investment in research and development; • High viscosity, acidity and high level of oxygenated compounds, which can corrode equipment (pyrolysis technology); • Risk of poisoning the catalysts in the synthesis stage (gasification technology); • Lack of competitiveness compared to mineral bunker fuel.
VEHICLE SHARING	
Transport (Road)	• Lack of norms and regulations for the large scale implementation of technology; • Resistance associated with behavioral changes for sharing mobility services; • Inappropriate use of vehicles due to the inexistence of ownership of the asset; • Test phase, with potential safety risks, for sharing automated and connected autonomous vehicles.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
NATURAL GAS FOR WATER TRANSPORTATION	
Transport (Waterways)	• Need to develop support infrastructure (supply); • Low level of technological maturity in motorization and storing natural gas on vessels; • High cost of developing the system to supply liquefied natural gas for vessels; • Competition for natural gas with the industrial and energy sectors.
USE OF NEW, LIGHTER MATERIALS IN VEHICLES	
Transport (Road)	• Low level of maturity of light materials for application in vehicles; • High cost of developing lightweight materials, with potential impacts on vehicle prices; • Applicability of materials in accordance with vehicle safety requirements; • Competition with other investments by vehicle manufacturers.
ELECTRIC TURBO-COMPOUND ENGINES	
Transport (Road)	• Lack of local technology content; • High cost of technology, with significant impacts on the final price of vehicles; • Increase in vehicle weight and size; • Competition with other investments by vehicle manufacturers.
SMART CONVOY SYSTEM	
Transport (Road)	• Low penetrability of the technology due to the exclusive application for heavy vehicles; • Resistance to change in the way vehicles are driven; • Lack of testing of the application of the technology worldwide; • Need to adapt the regulatory framework to revise new distance standards for vehicles.
FLEX HYBRID VEHICLES	
Transport (Road)	• Lack of technology standards; • Lack of local technology content in vehicle components; • High price for the final consumer; • Lack of a legal framework and specific lines of financing for electric vehicles; • Ignorance of the benefits of the technology.
PARTIAL OR TOTAL ELECTRIFICATION OF TRAINS	
Transport (Rail)	• High cost associated with support infrastructure (rail network); • Technological lock-in to the diesel powered train infrastructure; • Lack of local technology content in train electrification and hybridization components; • Lack of consensus on the optimal energy conversion technology; • Lack of technology standards.
MAGNETIC LEVITATION (MAGLEV) SYSTEMS FOR TRAINS	
Transport (Rail)	• High cost associated with infrastructure (rail network); • High cost of magnetic levitation trains; • Lack of local technology content; • Low technology readiness level globally, with applications only on short lines; • Lack of investment in research and development for the development of national technology.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
PARTIAL OR TOTAL ELECTRIFICATION OF VESSELS USING RENEWABLE ENERGY	
Transport (Waterways)	• High cost associated with providing infrastructure (supply); • Limited vessel autonomy; • Lack of local technology content for batteries; • Lack of applications at the national level; • Lack of consensus on the optimal energy conversion technology.
IMPROVEMENT OF AIRCRAFT AERODYNAMICS	
Transport (Air)	• Low level of technology readiness (prototype development stage); • Low local technology content; • High cost to develop the technology; • Lack of research and development at the national level.
ELECTRIFICATION OF AIRCRAFT USING RENEWABLE ENERGY	
Transport (Air)	• High cost associated with providing infrastructure (supply); • Low local technology content in electrical systems and batteries; • Lack of applications at the national level; • Lack of consensus on the optimal energy conversion technology.
PLUG-IN HYBRID ELECTRIC VEHICLES	
Transport (Cross-sectoral)	• Lack of consensus on the optimal energy conversion technology; • Lack of technology standards; • Lack of support infrastructure for recharging vehicles; • Lack of local technology content in the vehicle and component production chain; • Low level of technological development; • High final consumer price.
LIGHT BATTERY POWERED ELECTRIC VEHICLES	
Transport (Cross-sectoral)	• Lack of consensus on the optimal energy conversion technology; • Lack of technology standards; • Lack of support infrastructure for recharging vehicles; • Lack of local technology content in the vehicle and component production chain; • Low level of technological development; • High final consumer price.
BATTERY POWERED ELECTRIC BUSES	
Transport (Cross-sectoral)	• Lack of consensus on the optimal energy conversion technology; • Lack of support infrastructure for recharging vehicles; • Limited vehicle autonomy; • Lack of local technology content in the vehicle and component production chain; • Low level of technological development; • High cost for the acquisition of vehicles, with potentially higher transportation fares.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
HYDROGEN FUEL CELL ELECTRIC VEHICLES	
Transport (Cross-sectoral)	• Lack of consensus on the optimal energy conversion technology; • Lack of technology standards; • Lack of support infrastructure to store hydrogen and fuel vehicles; • Lack of local technology content in the vehicle and component production chain; • Low level of technological development; • High final consumer price.
ETHANOL FUEL CELL ELECTRIC VEHICLES	
Transport (Cross-sectoral)	• Lack of consensus on the optimal energy conversion technology; • Lack of technology standards; • Lack of local technology content and maturity level of power transistors; • Low level of technological development; • High final consumer price.
GENERATION OF ELECTRICITY FROM BIOGAS WITH MICROTURBINES	
Waste (Effluents, MSW and Agricultural)	• Lack of local technology content; • Need for dimensioning to operate with biogas and optimize the operation to improve efficiency; • Conflicting/or lack of information from decision makers about the benefits of the technology; • High capital, operating and maintenance costs; • Lack of regulatory instruments; • Lack of legitimacy and few successful initiatives in the country.
BIODIGESTION OF MSW FOR THE PRODUCTION OF ELECTRICITY AND BIOMETHANE	
Waste (MSW)	• Need to monitor biogas cleaning and treatment systems and to characterize waste in the country; • Low competitiveness of the products generated and development of the supply and service chain; • Lack of local technology content; • Lack of regulatory framework for the sale of biomethane; • High capital, operating and maintenance costs; • Need to incorporate distribution agents to increase the use of biomethane in captive fleets; • Resistance to the technology.
WASTE INCINERATION	
Waste (MSW and agricultural)	• Requires specification of waste and qualified labor; • Need to adapt emission treatment and monitoring systems; • Low competitiveness of the products generated and development of the supply and service chain; • Lack of local technology content; • High capital, operating and maintenance costs; • Lack of adequate commercial arrangements; • Resistance from different agents, due to emissions and the need to use recyclable waste; • Lack of good practices and successful cases in the country.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
PLASMA GASIFICATION OF MSW	
Waste (MSW)	• Lack of local technology content; • Need to specify waste; • Poorly developed technology and/or not adapted for application; • High capital, operating and maintenance costs; • Lack of success stories in the country and knowledge on how to use the equipment.
USE OF AGRICULTURAL AND AGRO-INDUSTRIAL WASTE	
Waste (Agricultural)	• Heterogeneity of the substrates; • Seasonal availability of agricultural waste; • Lack of a market for biogas; • Lack of a market for biomethane in the transport sector; • High capital, operating and maintenance costs.
PHOTOVOLTAIC SOLAR INDUCTION STOVES	
Buildings (Residential)	• Lack of technology value chains; • High cost of additional equipment for the induction stove; • Resistance to change in cooking behavior; • Ignorance of the benefits of the technology; • Lack of training for the installation and maintenance of systems.
RENEWABLE MICROGENERATION PLANTS: WIND MICROTURBINES, OPV AND THIN FILM CELLS	
Buildings (Residential, Commercial and Services)	• Lack of local technology content; • Poor efficiency in energy conversion. • High costs compared to conventional sources; • Competition with other investments; • High cost of capital and long-term return on investment; • Need for regulations for interconnection and certification contracts for equipment; • Possible impacts on the stability of the electrical system; • Lack of specialized labor for the installation and operation of equipment; • Lack of information about the benefits of the system.
SMART GRIDS	
Buildings (Residential, Commercial and Services)	• Uncertainties associated with the useful life of the equipment; • Need for new technological approaches to data processing, bidirectional communication and equipment integration; • Lack of local technology content; • Need to develop security guidelines for the use of the technology; • High cost of capital and long-term return on investment; • Need for changes in the regulations for the electricity sector to incorporate the technology; • Need for standardization and certification of the technologies involved; • Lack of good practices, successful cases in the country and knowledge of the benefits of the technology.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
NEW MATERIALS FOR ZERO ENERGY BUILDINGS (ZEB)	
Buildings (Residential, Commercial and Services)	• Need to optimize the use of automation systems; • Low local content in the technologies; • High cost of capital and long-term return on investment: • Need for certification of materials and technologies; • Lack of knowledge of the benefits of the technologies; • Need for training professionals, especially in the construction sector; • Lack of good practices and successful cases in the country.
PRECISION AGRICULTURE	
AFOLU (Agriculture)	• Limited connectivity, availability of interfaces and data security; • Low local content in AP technologies; • Poor accuracy in digital image processing; • High cost of equipment with high technological content; • Lack of specific regulations to encourage the adoption of PA; • Lack of practical and intuitive tools; • Lack of training in PA, due to inadequate rural technical assistance.
CARBON ALTERNATIVES TO NITROGEN, PHOSPHORUS AND POTASSIUM (NPK)	
AFOLU (Agriculture)	• Few types of inoculants available on the market; • Need for studies on the potential of biological nitrogen fertilization for different crops, climatic conditions and management in the country; • Insufficient rural technical assistance; • Low technology readiness level of alternative sources of potassium and potassium thermophosphates; • Conservatism among landowners.
AGRICULTURAL GENETIC IMPROVEMENT WITH ROBOTIC PHENOTYPING	
AFOLU (Agriculture)	• Technique not disseminated in agriculture; • Low local content in plant phenotyping; • Lack of investment in research and development; • Insufficient rural technical assistance; • Resistance among rural producers to long-term investments; • Niches of cultural resistance to the production and consumption of genetically modified organisms; • Conservatism among rural landowners; • Uncertain return on investment.
GENETIC IMPROVEMENT IN BEEF CATTLE	
AFOLU (Livestock)	• Lack of standardization in data collection procedures; • Lack of integration and agility between agents involved in genetic improvement programs; • Differences between production systems; • Uncertain return on investment; • Insufficient rural technical assistance; • Ignorance of the economic importance of animal characteristics; • High cost to access genetic improvement platforms.

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SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
NUTRITIONAL SUPPLEMENTATION	
AFOLU (Livestock)	• Lack of knowledge for using the technique; • Lack of capital to invest in nutritional supplementation; • Insufficient rural technical assistance; • Ignorance of the benefits of the technology; • Conservatism in the sector; • Lack of regional logistics for the distribution of supplements._
PRECISION FORESTRY AND SILVICULTURE	
AFOLU (Other land uses)	• Lack of technological development in territorial intelligence systems; • Limited connectivity, availability of interfaces and data security; • Lack of local technology content in precision forestry and silviculture; • Poor accuracy in digital image processing; • Ignorance of territorial intelligence technologies; • Lack of training in the use of the technologies, due to lack of rural technical assistance.
MIXED PLANTING SILVICULTURE WITH EXOTIC AND NATIVE SPECIES	
AFOLU (Other land uses)	• Lack of investment in research on mixed planting silviculture; • Dependence on a large scale for production; • Insufficient rural technical assistance; • High cost of inputs, transport and implementation of mixed planting systems; • Lack of labor in the field.
GENETIC IMPROVEMENT OF FORESTS	
AFOLU (Other land uses)	• Uncertain return on investment • Lack of investment in research and development; • Level of technological maturity limited to experimental applications (and mostly for exotic species); • Conservatism among rural landowners; • Need for strict controls due to the reduction of genetic variability; • Insufficient rural technical assistance; • Resistance to long-term investments among rural producers.
SILVICULTURE WITH NATIVE SPECIES FOR RESTORATION	
AFOLU (Other land uses)	• Level of technological maturity limited to experimental applications (and mostly for exotic species); • Insufficient rural technical assistance; • Resistance to long-term investments among rural producers; • Uncertain return on investment; • Lack of investment in research on native species silviculture; • Dependence on large scale for production; • Insufficient rural technical assistance; • Lack of labor in the field.

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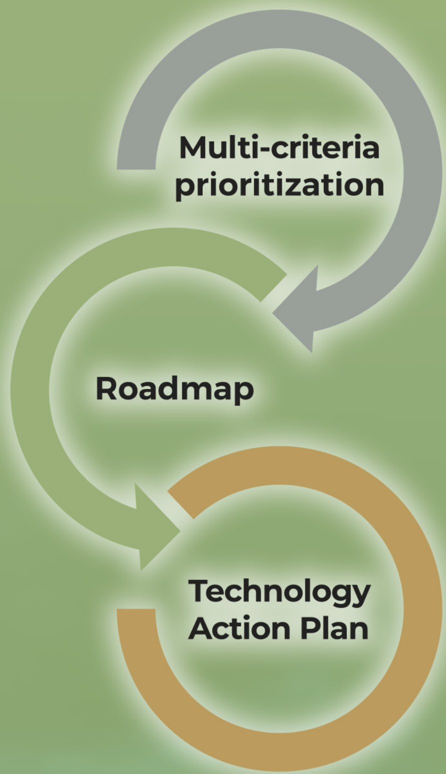
SECTOR (SUB-SECTOR)	TECHNOLOGIES AND MAIN BARRIERS
CONSERVATION AND GENETIC IMPROVEMENT OF NATIVE SPECIES	
AFOLU (Other land uses)	• Low level of technological maturity in population genetics, flowering and fruiting phenology and forest production; • Insufficient rural technical assistance; • Lack of investment in research; • Lack of local technology content and high cost of reagents and equipment; • Ignorance of the benefits of the technology, especially in the private sector; • Resistance to long-term investments among rural producers; • Uncertain return on investment.
SATELLITE MONITORING	
AFOLU (Cross-sectoral)	• Lack of investment in basic and applied research related to high resolution images; • Limited availability of high resolution images; • Lack of local technology content in satellites; • Insufficient rural technical assistance; • Lack of investment in national satellite technology and image processing methodologies; • Ignorance of territorial intelligence technologies; • Lack of training in the use of the technologies.
VALIDATION SYSTEMS FOR THE RURAL ENVIRONMENTAL REGISTRY	
AFOLU (Cross-sectoral)	• Big Data not sufficiently developed, including analysis of land, hydrology and land use and land cover data • Need to establish specific state standards for validation; • Lack of investment in technology, human resources and infrastructure; • Lack of investment in national satellite technology and image processing methodologies; • Ignorance of territorial intelligence technologies; • Lack of training in the use of the technologies applicable to the validation of the Rural Environmental Registry (*Cadastro Ambiental Rural - CAR*).
CERTIFICATION SYSTEMS FOR CHAINS THAT ARE DEFORESTATION-FREE	
AFOLU (Cross-sectoral)	• Insufficient rural technical assistance; • Technology readiness Level of agricultural product certification systems still experimental; • Lack of investment in certification systems for agricultural products; • Agricultural production certification systems limited to the Amazon biome; • Lack of investment in basic and applied research related to high resolution images; • Availability of high-resolution images limited to the Amazon biome; • Lack of investment in national satellite technology and image processing methodologies; • Ignorance of territorial intelligence technologies; • Lack of training in the use of the technologies; • Dependence on CAR environmental validation systems for certification of deforestation-free chains in agricultural production.

Source: the author.



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