ASSESSMENT OF BRAZIL'S POTENTIAL IN THE ENERGY TRANSITION

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Abstract

The Energy Transition from fossil fuels to renewables is reshaping the countries' energy mix to reduce GHG emissions and cope with Paris Agreement goals until 2050. China, the EU, and the USA are leading this race through new technology development, electrification of its systems, and securing critical materials. The success of this change on a global scale will depend to a large extent on how fast emerging countries will be able to keep pace and accelerate their energy transitions, balancing their economic, social, and environmental issues. In this context, Brazil could play an important role, not only with its natural resources and renewable potential but also in promoting locally developed technologies mostly based on bioenergy. This article aims at exploring Brazil's development and potentialities in the following technologies: (i) Hydrogen, (ii) Biofuel Cell, (iii) Sustainable Aviation Fuel (SAF), (iv) Bioenergy with Carbon Capture and Storage (BECCS), (v) Sugarcane Ethanol, and (vi) Solar Photovoltaic (PV). The methodology was based on a literature review and a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for the above-mentioned technologies.

Keywords

Energy Transition; Renewable Technology; Climate Change Mitigation; SWOT; Brazil;

1. Introduction

As societies evolved in the last century, the standard of living is increasingly dependent on the type of energy sources and the intensity of their use. This makes the current changes required for the transition from fossil fuels to a more sustainable energy matrix a hefty endeavor. To reduce anthropogenic Greenhouse Gas (GHG) emissions associated with the climate emergency (Change, 2018) and cope with the Paris Agreement goals (Agreement, 2015) a conscious effort must be made to leave cheaper primary energy sources for a renewable and overall, less abundant paradigm.

This issue is especially challenging for emerging economies that intended to use their natural resources to ramp up industrialization and reach the development levels of more affluent nations. Besides, specific socio-economic groups, such as poor and middle-income households, can be affected by higher food and energy prices due to the phaseout of fossil fuels and carbon taxation (Gambhir et al., 2018).

As developing countries now have their path restricted despite that rich countries were able to develop without such constraints in the past, the concept of just transition emerged, to balance environmental concerns with socio-economic goals. The Paris Agreement allowed nations to establish Nationally Determined Contributions (NDCs), in which each nation can outline its offering for the overall goal of GHG emissions reduction. Nations can assess and define their priorities by considering local conditions and objectives. The capacity for selecting the route for sustainability that balances socio-economic and environmental issues has opened for nations a diverse range of technological opportunities. A well-adjusted selection of climate change mitigating technologies can go beyond achieving its specific environmental goal and instead of being a burden, it can promote social development and economic growth.

This work focused on assessing opportunities for Brazil in the energy transition framework taking into account natural resources potential and local-developed technologies. It was also considered in this work the need for a more technology-focused approach instead of merely feedstock and renewable energy exploitation strategy to avoid the current international labor division based on the technological capability that limited Brazilian development in the past and has shaped inequality and dependency between countries in today’s global economy.

2. Methodology

This work uses the set of climate technologies that are available and regarded as applicable for Brazilian mitigation and adaptation efforts. It is important to stress that this selection is not an exhaustive list of potential technologies that can be applied, but rather a specific set selected at the authors' discretion. A complete set of mitigation and adaptation technologies can be found in the Technology Needs Assessment (TNA) Project of the United Nations Framework Convention on Climate Change (UNFCC). In turn, the TNA Project takes the Sustainable Development Goals (SDG) and the Paris Agreement as starting points to define, by a local-based assessment, the technologies more suitable for a country's specific climate change situation (UNFCC, 2022). An official report on the Brazilian climate mitigation action plan (MCTI, 2021), based on the TNA and sanctioned by the Brazilian Government, and the United Nations Environment Programme (UNEP), was published in 2021 and also, Da Silva et al. (2022) have published the study on this assessment.

For this work the criteria for the selection of technologies were: (i) energy-related technologies, (ii) that take advantage of Brazilian's natural resources, and (iii) can be applied and have the potential to improve Brazilian's current technological framework. After an initial evaluation that determined plenty of candidate technologies that meet the criteria, six technologies were chosen for a more detailed examination.

The technologies were assessed by literature review regarding socio-economic, technological, and application potential for Brazil. Finally, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was used for each technology to summarize and offer some insight considering the prospect of adoption of the referred technologies in Brazil to promote a tailor-made strategy for Brazil in its energy transition process.

3. Technologies Review

The technologies chosen for the evaluation of this work are (i) Hydrogen, (ii) Biofuel Cell, (iii) Sustainable Aviation Fuel, (iv) Bioenergy with Carbon Capture and Storage, (v) Solar Photovoltaic, and (vi) Sugarcane Ethanol. In the next sections, these technologies are examined in detail.

3.1. Hydrogen

Hydrogen is the simple and the most abundant element in the universe. Although rarely found on Earth in molecular form, it is present in compounds like water, fossil fuels, and a variety of biomasses. As a fuel, it is considered an intermediary source of energy, or energy vector, which needs to be separated from other elements, stored, and transported to be useful.

One of the main advantages of hydrogen as a fuel is that it has clean use, when consumed in a fuel cell, having as byproduct only heat and water. On the other hand, producing molecular hydrogen is a very energy-intensive process. It can be obtained mainly through methods such as Electrolysis, Steam Methane Reforming (SMR), Autothermal Reforming (ATR), Partial Oxidation, Gasification, and Pyrolysis, with the possibility of use of Carbon Capture and Storage (CCS) technology to reduce GHG emissions when it applies (Noussan et al., 2020). Hydrogen can be classified under a color scheme to show its technological route which considers the feedstock, the energy source, and the use of CCS (Guariero et al., 2022). For instance, hydrogen produced in an electrolysis process uses water as feedstock and can be Green (when it uses renewable energy), Pink (when it uses nuclear energy), or Yellow (when it uses mixed energy from the grid). These hydrogen routes do not have direct GHG emissions in their production process, although Pink hydrogen has as byproducts the nuclear waste, and Yellow hydrogen has to account for indirect emissions from the energy source used. When hydrogen is produced through the SMR, ATR, partial oxidation, or gasification routes it can be Muss (when it uses biogas or biomasses as feedstock), Gray (when it uses natural gas), Brown/Black (when it uses oil or coal), or Blue (when CCS is applied). The Muss, Gray and Black/Brown hydrogen classifications have GHG emissions in their production processes, although with an energy cost penalty, those emissions can be significantly reduced by the use of CCS, and the hydrogen is renamed Blue. Finally, hydrogen produced in a Pyrolysis process uses natural gas as feedstock and is called Turquoise hydrogen. It does not have direct GHG emissions, producing as a byproduct solid carbon. However, emissions in the Pyrolysis process may exist due to the energy source used (Akaev & Davydova, 2021; Noussan et al, 2020).

The hydrogen processing and supply chain is long and complex and includes multiple steps which translate into a low Energy Return On Energy Invested (EROEI). Hydrogen transport requires significant energy costs, either to compress, liquefy, or convert to ammonia or another carrier. It is also possible to transport it through hydrogen-designed pipelines or to blend hydrogen in existing natural gas grids, however, costs and safety must be addressed due to hydrogen's natural properties. (Noussan et al, 2020).

Strategic approaches for building a new energy paradigm based on hydrogen have been developed over the world in the last few years. Between 2017 and 2021, the Europe Union, Australia, Canada, Chile, Japan, Norway, South Korea, and other nations introduced their expansion plans for hydrogen production and use for the next decades (Akaev & Davydova, 2021). In turn, in July 2021 Brazil created its Hydrogen National Program that aims to promote the technology and position the country competitively on the international stage. The development principles adopted are based on valuing the national potential of energy resources; being comprehensive in considering the diversity of energy sources and potential for production, logistics, storage, and use of hydrogen; aligning the economy decarbonization goal; encouraging the development of local-based hydrogen technology; establish a competitive market, considering domestic demand and exports, seek synergies with other countries; and integrate the hydrogen in the national chain of raw materials and production. The steel, petrochemical, and fertilizer industries are identified as potential major consumers of this new energy vector (MME, 2021a; Reset, 2022).

In the context of the energy transition from fossil fuels, some form of energy storage will play an essential role, given the intermittence of renewable energy sources. Hydrogen technologies with net-zero or low GHG emissions have made many advances and present themselves as interesting solutions, although they are not yet at a stage of large-scale implementation. New solutions using hydrogen that include storage, distribution, and use are constantly being presented (Kovač et al., 2021). For the storage of low-cost energy generated by renewable sources, hydrogen can be competitive with batteries (Armaroli & Balzani, 2016; Pellow et al., 2015). This use can be an option for a combined renewable-storage system in the absence of a more efficient combination (such as hydroelectric for storage). Besides, there are specific niches where hydrogen makes sense and can be used efficiently. The use of hydrogen in fuel cells for maritime or heavy land transport is promising and is currently being studied and tested. Also, hydrogen has applications in the steel, cement, petrochemical, and fertilizer industries, as prices of net-zero or low GHG emission hydrogen become more competitive.

Table 1 – Hydrogen SWOT analysis

SWOT	Helpful	Harmful
Internal	**Strengths** ● Water availability; ● Renewable potential (green and blue hydrogen); ● Port infrastructure and basic logistics; ● Hydrogen National Program; ● Technological and human resource capabilities in similar field (oil and gas sector).	**Weaknesses** ● Lack of competitiveness as a vectors; ● Lack of specific distribution, and storage infrastructure; ● Lacks of competitiveness in production technology; ● Complex and low maturity technology.
External	**Opportunities** ● Cost reduction due to economies of scale, and scope; ● Energy storage for renewable; ● Exports to external markets; ● Substitution of feedstock in the steel, cement, petrochemical, fertilizer industries, and fuel in maritime and heavy land transport.	**Threats** ● Absence of a significant consumer market; ● Climate change disrupts water availability; ● Risk of become a commodity export-oriented development.

3.2. Biofuel Cell

The electrification of transport has undergone major changes over the last decade with the increasing insertion of Battery Electric Vehicles (BEVs) and Plug-in Hybrid Vehicles (PHEVs) in fleets, especially urban ones. Despite the dominance of batteries in the expansion of electromobility, restrictions related to the production chain of storage systems pose great challenges in the long term. On a smaller scale, FCEVs (Fuel Cell Electric Vehicles) have been gaining ground and have been on the market for about a decade, largely limited by the lack of capillarity of hydrogen refueling stations (IEA, 2022).

Running behind the fuel cell hype, biofuel cells are at an earlier stage of technological development and offer a great advantage as an alternative car propulsion technology in countries that produce ethanol. The Solid Oxide Fuel Cell (SOFC) was developed to use biofuels directly in the anode and allow the oxidation reaction.

In addition to having a low carbon footprint and contributing to the decarbonizing transport sector, biofuel cells, based on SOFC technology, benefit from (i) the direct use of biofuels, available in Brazil such as ethanol, without the need to produce and store hydrogen

(ii) potential vehicle weight reduction (iii) fast recharging (iv) use of the existing fuel infrastructure (v) in comparison to the H2 cell, it uses lower cost materials to manufacture the tank, for example of platinum (vi) efficiency gain and reduction of the technological complexity of the process since it is not necessary to purify the synthesis gas.

As per (IEA 2022) emerging markets still need to catch up with the decarbonization of the transportation sector,

> "Broadening the deployment of EVs in these countries/regions face additional challenges. For example, their stock may be heavily dependent on second-hand vehicles with EVs becoming available with a time lag. Deployment of charging infrastructure may be inhibited in regions with weak grids. Few have established emissions standards, or they may be too low to serve as a driver to spur EV uptake" (IEA 2022).

In this sense, biofuel cells can become a breakthrough technology to accelerate transportation transition and therefore reduce emissions from light and heavy-weight vehicles, especially in markets benefiting from ethanol production and existing infrastructure. In the case of Brazil and other emerging economies, where the expansion of electromobility is still limited, regulatory and development policies could be designed in a customized way to not only efficiently promote leapfrog for a low carbon economy, but also leveraging on competitive advantages to the detriment of a situation of external technological and commercial dependence.

Studies presented by EPE (2018), show that a path to electromobility in Brazil could be done smoothly, in the coexistence between hybrid, electric, and ICE vehicles, in which the latter would have a long resilience due to the low prices. On the other hand, in a scenario of strategic transition, public policies of full replacement could be adopted, using legal and regulatory arrangements that allow the customization of the transition, with the use of biofuel cell vehicles. In this context, biofuel cell development up to a commercial scale could represent a great advance to a green economy but also an opportunity to promote qualified economic growth.

In Brazil, the technology of SOFC using ethanol as fuel is in relative advance development, with a proven technological concept and incorporating all electrode and cell tests[1]. The next steps demand engineering and investment can be taken to industrial production. Given this scenario, Brazil shall increase efforts in fuel cells powered by biofuels as one of the champion technologies that would promote electromobility and favor its endogenous comparative advantage from sugar cane ethanol production and infrastructure.

[1] Studies and tests at the Hydrogen Laboratory of COPPE/UFRJ are in TRL5.

Table 2 – Biofuel Cell SWOT analysis

SWOT	Helpful	Harmful
Internal	**Strengths** • Large ethanol production; • Infrastructure available; • Large scale agriculture sector with high competitiveness; • Higher efficiency than ICE; • Succeed flex fuel strategy.	**Weaknesses** • Lack of financing for the technology; • Low progress on engineering and production scale; • Lack of electromobility strategy and political support.
External	**Opportunities** • Accelerate electromobility process; • Customize electromobility strategy; • Drive technological process and export; • Leverage on ethanol production and infrastructure; • Explore cooperation with China and India.	**Threats** • Electromobility dependency of mainstream technologies; • Risks associated with land use change (due to ethanol); • Competition with Electric Vehicles.

3.3. Sustainable Aviation Fuel (SAF)

The aviation sector was responsible for 2.1% of global CO2 emissions in 2019 (ATAG 2020). Despite the low percentage, the trend is the sector's recovery after the decline caused by the COVID-19 pandemic. And to contain the increase in GHG emissions, ICAO 1 launched the CORSIA 2 program, whose objective is to achieve carbon-neutral growth concerning the sector's emissions considering the year 2020. One of the ways to reduce the sector's emissions is through the use of SAFs.

The generic name SAF represents a set of renewable fuels that have been studied and developed with the aim of fully or partially replacing aviation fuels of fossil origin, especially aviation kerosene. The SAF alternatives are drop-in types, not require adaptation of the aircraft or its engines. These renewable alternatives can be produced from different feedstock and through different technological routes.

The feedstock of aviation biofuel can be vegetable oils (from soybean or palm, for example), animal fats, corn, sugar cane, municipal solid waste, wood residues, straw, residual gas from industrial processes, and residues of plastics and tires, among others.

Technological routes for SAF production need to be able to produce a fuel with characteristics similar to petroleum-derived aviation kerosene, especially given the characteristics of high efficiency and low freezing point. To ensure properties like these, SAFs are evaluated by ASTM International (American Society for Testing and Materials), which certifies the processes for converting biomass into biofuels to be used in commercial aviation. According to ICAO (2021), 9 technologies had already been approved by ASTM by October 2021.

Of these, 4 are the most consolidated and will be summarized below (Ng et al., 2021):

(i) Fischer Tropsch synthesis (FT) - the biomass is gasified into syngas. This gas is converted by an FT synthesis process into liquid hydrocarbons.

(ii) Hydroprocessed esters and fatty acids (HEFA) – use vegetable oils and animal fat in hydroprocessing to formulate aviation biofuel. In this process, hydrocarbons are obtained via hydrogenation, hydroisomerization, and hydrocracking until obtaining paraffinic kerosene.

(iii) Alcohol-to-Jet (ATJ) – alcohol can be obtained from biomass via a thermochemical or biothermochemical route. This alcohol can be transformed into aviation biofuel in two pathways: (a) dehydration, oligomerization, and hydrogenation; (b) technology developed by Exxon-Mobil to transform methanol into olefin and then into gasoline.

(iv) Hydroprocessing of Fermented Sugars (HFS) – route of biochemical conversion of fermented sugars into synthesized iso-paraffin (SIP). The resulting hydrocarbon can be mixed in a proportion of up to 10% of the fossil fuel.

It should be noted that, so far, the SAFs already approved are allowed to be mixed with traditional fuel in a proportion of a maximum of 50% (ICAO, 2021). Another important observation is that one of the main inputs of the SAF is hydrogen, so to reduce the carbon footprint of this fuel, the ideal is that this hydrogen does not come from a fossil source.

Two of the major challenges for the production of SAF on a commercial scale are the availability of good quality feedstock in sufficient amounts, infrastructure for the flow of feedstock to the processing plants, and the cost structure of production, given that the existing sustainable aviation fuels options still cost two to seven times as much as fossil fuel (Dodd & Yengin 2021). Added to this is the fact that fuel is the most relevant cost item for airline operators (Milanez, et al., 2021).

Brazil has the advantage of having a path already covered in the area of biofuels since the1970s, with programs such as the National Alcohol Program, the National Program for the Production and Use of Biodiesel (2005), and the National Biofuels Policy, RenovaBio (2017). With this history, Brazil has established itself as one of the world's largest producers of ethanol and biodiesel (BP, 2022) and part of this existing infrastructure for biofuels can be used for the production of SAF.

In addition to contributing to lower emissions, SAFs have the advantage of the possibility to have almost no cost or environmental impact at the feedstock collection sites, depending on which they are. However, SAF production in Brazil, as in the rest of the world, still faces economic and environmental challenges. Therefore, the country's first commercial-scale SAF projects are still being developed to start production in 2023, such as the pilot plant in Paraná, the result of a partnership between the German Agency GIZ and the International Center for Renewable Energy (EPBR, 2022). In addition, Petrobras announced this year the completion of the production test by co-processing fossil-based kerosene and vegetable oil, using existing refining units, being the first test of this type in Brazil (EBC, 2022).

In 2021, the Roundtable on Sustainable Biomaterials (RSB) prepared a study to identify potential feedstock in Brazil, focusing mainly on waste availability and strategic locations for the production and consumption of SAF in the country. According to this report, the most suitable materials for Brazilian conditions would be sugarcane residues - bagasse and straw - and wood residues from eucalyptus cultivation, which are currently abandoned in the field (RSB 2021). Through the FT and ATJ routes, the study concluded that Brazil has the potential to produce around 9 billion liters of SAF per year, higher than the consumption of 7 billion liters in 2019, the pre-pandemic period (ANP, 2022). The use of sugarcane bagasse and straw and wood residues have the advantage of being alternatives that would not increase pressure on land use and food production.

Nonetheless, for the development of this market in Brazil, public policies are needed to provide a safe environment for investments. In an evolution towards a regulatory framework, in 2022 the Ministry of Mines and Energy (MME) launched a set of premises for the future SAF policy, within the scope of the Fuel of the Future program. Among the premises is that the mandate will be based on the sector's emission reduction targets (MME, 2022). This reduction target will be 1% per year starting in 2027, the year in which CORSIA's mandatory emissions compensation regime begins. On the other hand, this set of assumptions also signaled the possibility of Brazil importing SAF, which brings security to the demand side, but insecurity to the supply side.

Table 3 – Sustainable Aviation Fuel Cell SWOT analysis

SWOT	Helpful	Harmful
Internal	**Strengths** ● Abundance of feedstock, as sugarcane residues and wood residues, with close to zero cost and low emission at the collection site; ● Large scale agriculture sector with high competitiveness; ● Infrastructure established for the production of biodiesel and ethanol; ● Technological feasibility.	**Weaknesses** ● Low maturity of regulation in Brazil; ● High cost production compared to fossil fuels.

	Opportunities	Threats
External	● Potential surplus can promote exports and lead world SAF production; ● Decarbonize air transportation, addressing mandatory phase of CORSIA in 2027; ● Implement BECCS leading to negative emissions.	● Late engagement in SAF development; ● Inability to reach competitiveness; ● If the green hydrogen industry and the SAF industry do not evolve at the same pace; ● Risks associated with land use change.

3.4. Bioenergy with Carbon Capture and Storage (BECCS)

The term BECCS refers to the concept of combining bioenergy applications (including all forms of power, heat, and fuel production) with Carbon Capture and Storage (CCS). Since biomass can withdraw and store atmospheric CO2, the gas released during biomass conversion can be captured and stored permanently, thus depriving the atmosphere of CO2 (Torvanger, 2019).

The BECCS chain consists of three main processes (Arasto et al., 2014):

(i) Capture and separation of CO2 present in gas streams from stationary emitting sources - can occur through several methods, such as absorption, adsorption, and membrane capture (IPPC, 2005). CO2 capture can be applied to a range of technologies, like dedicated or co-firing biomass in power plants, combined heat and power plants, ethanol plants, biogas refineries, and biomass gasification plants (Torvanger, 2019).

(ii) Transport of CO2 to the storage location, when necessary - In general, greater efficiency in the transport of gases over medium and short distances is through pipelines, however, depending on the conditions and scale of the projects, it can be carried out by land or water transport (IPPC, 2005).

(iii) CO2 storage - can be done via some technological options: storage at great depths in the oceans, mineral carbonation, and storage in geological reservoirs (IPPC, 2005).

Although the same technology from CCS is applied to BECSS, since biomass has removed CO2 from the atmosphere during its growth process, BECCS can represent a negative source of emissions. Also, as the flue gases generated from biogenic source plants consist of almost pure CO2, CO2 capture can become less expensive and more efficient compared to other processes (Arasto et al., 2014). The scientific frontier for the advancement of CCS and BECCS technology is the development of methods to capture CO2 from sources. There is ongoing research on the use of microalgae (Pratama et al. 2019), the development of more efficient amines for absorption, and new adsorption methods and membranes. However, there is currently no technological challenge for the implementation of BECSS, its biggest obstacle is the economic viability - since carbon pricing is not consolidated - and the absence of regulation.

Most climate change mitigation pathways that limit global warming to 2 °C rely on negative emission technologies, in particular BECCS. In the energy sector, CCS appears as a key tool to mitigate CO2 emissions (IPCC, 2014). This view has been reiterated several times by the IEA and IPCC (IEA, 2016; IPCC, 2018), noting that CCS should be used in conjunction with other mitigation options. The biofuel production plants are an important source of CO2 emissions, which makes the ethanol fermentation process an initial opportunity to implement BECCS due to its low capture cost. As a major ethanol producer (second in the world), Brazil is in a privileged position to develop this technological option (Tagomori et al. 2018), being another favorable condition the estimated extensive geological storage capacity of the country, 2000 Gt of CO2 (KETZER et al., 2016).

In this context, da Silva et al. (2018) proposed an optimization methodology to estimate the abatement costs of capturing and transporting fermentative CO2 from ethanol distilleries to oil fields in Brazil. The results ranged between 32 and 87 US$/t CO2. Despite the good conditions for BECCS development, the current scenario results in a high abatement cost mainly due to the transport of CO2 from sources to sinks, which was mainly attributed to the small scale of the distilleries, the low capacity factor of the pipelines related to seasonal production of ethanol and the high capital costs of offshore pipelines.

The lack of specific legislation and economic incentives makes it difficult to advance BECCS implementation. A new perspective for BECCS should emerge with carbon pricing and the consolidation of a robust market and the insertion of public policies to reduce emissions. Another discussion point is that the sustainability analysis and engineering challenges for large-scale implementation of BECCS remain as a knowledge gap (Torvanger, 2019). Its biophysical feasibility, environmental effects, and impacts on biodiversity have been a discussion, taking into account the intensive use of land, water, and nutrients (Hanssen et al., 2020) with a special concern for the emissions related to land use change and food security associated to biofuel production.

Despite the challenges to BECSS application in the currents situation, the perspective of a developed carbon market and the biofuel Brazilian vocation, including the new technologies development associated, make BECCS an important path to Brazil achieving its NDC target once it figures as a critical share of the feasible negative emissions, providing benefits globally to tackle the climate emergency. With the perspective of the development of new technologies in the energy transition horizon that includes the increase in the production of biofuels, the BECCS implementation is a very interesting technique to be developed with.

Table 4 – Bioenergy with Carbon Capture and Storage SWOT analysis

SWOT	Helpful	Harmful
Internal	**Strengths** • Large ethanol production and installed industry; • Technological feasibility; • Large geological storage capacity.	**Weaknesses** • Small scale and spatial dispersion of emission sources; • High cost of CO2 transportation; • Absence of regulation; • Energy penalty.

	Opportunities	Threats
External	• Cost reduction due to economies of scale, and scope; • Lead negative emissions market; • Perspective of biofuel demand increase; • Biofuel international attractiveness due to BECCS.	• Climate change disrupts water availability; • Extremely dependent on regulation and carbon market development .

3.5. Solar Photovoltaic (PV)

Solar photovoltaic (PV) is a well-known technology among renewable energy sources. They are made of photovoltaic cells, grouped in modules, which convert sunlight into photovoltaic electricity. The whole system generally includes an inverter, and a controller and can operate with a battery coupled (Sumathi et al., 2015). An important characteristic of those systems is the variability and uncertainties of power generation due to the day/night cycle, radiation's dependence on latitude, weather conditions, and other issues.

In terms of GHG emissions, the PV system has no impact on the climate during power generation; however, significant CO2 emissions can be accounted for when considering the upstream production chain in a life cycle assessment. Constantino et al. (2018) demonstrated that life cycle GHG emissions from PV solar systems are very dependent on the electricity grid matrix from the country where the modules are produced. They also concluded that if implemented in Brazil, a country with a low emissions electric power grid, the Chinese-produced PV solar system would probably increase the emissions of the grid in a lifecycle-based analysis. On the other hand, Pinto et al. (2020) found in their carbon life cycle analysis that PV systems installed in northeast Brazil are beneficial to climate mitigation even if manufactured in China. It corroborates with the previous study of Filho et al. (2016), although they calculated that the mitigation would be 5 times greater if the PV was manufactured in Brazil or installed off-grid in an isolated area.

Even though the divergence between studies, understanding the role of carbon footprint in solar PV installed in Brazil is fundamental to elaborate public policies to meet the targets committed towards NDC and selected SDGs. In addition to climate mitigation, solar PV might present a high labor intensity and low consumption water footprint (IRENA & ILO, 2021; Mekonnen et al., 2015).

Since solar PV were developed, they have increased the range of sub-technologies used and improved their system efficiency. Particularly in the last decade, these improvements along with a mix of public policies provided significant cost reductions and a large expansion in installed capacity worldwide (Elgamal & Demajorovic, 2020; Jean et al., 2015). The global installed capacity increased from 72 GWp in 2011 to 848 GWp in 2021, led by China (39%) and followed by the USA (11%), Japan (9%), India (6%), and Germany (4%). Brazil ranked the tenth position reaching 1.7% of the world expansion in the period (IRENA, 2022). Despite the PV installed capacity outlook, the production chain of PV systems is even more concentrated in China, where 80% of the polysilicon, 85% of the cells, and 75% of world PV modules are manufactured (IEA, 2021).

The Brazilian PV net addition is not as expressive as the Chinese and the Indian ones, nonetheless, the role of Brazil in solar PV expansion is soaring and reached the fourth position in installed capacity added in 2021 (IRENA, 2022). The country's size and latitude ensure a great potential for solar PV energy presenting large available areas with high levels of insolation. However, a lack of strategic public policies in Brazil is pointed out as a disadvantage to the growth of this source compared with leading countries.

A significant encouragement in Brazil to invest in solar PV today is the distributed micro and mini generation (DG) which enables the consumers to become also producers and transfer to the grid the surplus generated energy to be compensated later. Although the DG is a great incentive, Luna et al. (2019) analyzed the growth of Brazilian distributed generation and concluded that regulatory improvements are needed to boost this market. They suggested taxes reductions on equipment, allowing more flexibility to the consumer, and inclusion of a DG requirement in housing programs.

Beyond the conventional system, an interesting emerging technology that Brazil would have advantageous potential is the floating PV on water bodies which could be more efficient than the conventional PV and reduce evaporation in reservoirs. Padilha et al. (2022) estimated that the Brazilian technical potential of this technology would meet 16% of electricity demand if 1% of total suitable areas were explored, however, they indicated the need for further research for broader adoption of the technology.

In another study of opportunities and issues for the PV expansion in Brazil, Elgamal & Demajorovic (2020) remarked that financial and fiscal incentives are very important to the blooming of the PV source and highlighted that despite other countries, the renewable peculiarity of Brazil's electric power grid contributes to low motivation on increasing PV installed capacity as a climate change mitigation measure. A well-established national PV production chain would provide a gain in terms of climate change mitigation and induce this increase, as the carbon footprint of modules could be reduced due to the lower emission factor of the grid.

Upon the broad range of PV sub-technologies being produced, two main categories of cells could be emphasized: the wafer-based cells, including the crystalline silicon cells that corresponded to about 95% of the PV market share in 2021; and the thin-film cells which corresponded to the other 5% (Fischer et al., 2022). Several studies seem favorable to Brazil investing in a PV national production chain either because of carbon footprint reduction or because the country has a huge stock of quartz minerals from which silicon could be obtained (Constantino et al., 2018; Filho et al., 2016; Moehlecke & Zanesco, 2012; Pinto et al., 2020). On the other hand, some organizations believe that the high investments needed, and the complexity of the solar-grade silicon processing are large barriers that could be only surpassed with a huge subsidy. In a reasonable scenario with large internal PV market growth, it would be less challenging to gain scalability and sustain a national production chain and expand internal R&D projects in the sector. In any case, an intermediate alternative suggested is the importation of cells and investments in the local assembly capacity of the modules (Elgamal & Demajorovic, 2020).

Table 5 – Solar Photovoltaic SWOT analysis

SWOT	Helpful	Harmful
Internal	**Strengths** ● No emission from power generation; ● Low cost generation; ● Large available areas with high insolation; ● Availability of quartz minerals.	**Weaknesses** ● High variability and uncertain generation; ● Fragmented public policies.
External	**Opportunities** ● Job creation to address a PV module supply chain; ● Reduction of water losses in reservoirs and no land competition whether is a floating system; ● Develop a local supply chain; ● Local production would reduce carbon footprint in life cycle assessment.	**Threats** ● Concentrated global production chain – dependence on China subject to other disruptions (demand, exchange rate); ● Difficulties related to market and scalability.

3.6. Sugarcane ethanol

Ethanol production can be done from several biomass types. The U.S., for instance, the biggest global producer, does it from corn. In Brazil, the second biggest producer, ethanol is made from sugarcane, already been cultivated in the country since the colonial periods (Bortoletto & Alcarde, 2015).

Sugarcane ethanol motor vehicles, however, began to gain importance in Brazil in the late 70's, after the first oil crisis impacted the Brazilian economy. The development of this industry was influenced by government policies aiming to reduce the foreign oil products dependency with the ProÁlcool Program, launched in 1975. After some phases, this program lost relevance, mainly after oil prices lowered on the international market. Only at beginning of this millennium, with the introduction of flex-fuel vehicles, ethanol gained relevance once again on the national energetic matrix. Currently, most of the Brazilian light vehicle fleet is from this kind of vehicle, able to run with any ratio of gasoline and ethanol (Rosillo-Calle & Cortez, 1998; Soares & Junior, 2021; Alcarde, 2008; Alves, Franco, Zanetti, & Góes, 2021).

Environmental and political pressures faced by the automobile industry in the last decades forced it to invest in technological changes to reduce its emissions. The use of biofuels, such as Brazilian ethanol and the introduction of flex-fuel vehicles, took an important role in this process. However, restricting access to biofuels oriented the industry to pursue other solutions, such as hybrid and electric vehicles, leaving biofuels a restricted role in future climate ambitions (Gonçalves, 2017).

For the Brazilian scenario, however, biofuels, mostly ethanol, still present some important advantages. In 2019, it was introduced a new federal policy called RenovaBio, aimed at promoting the expansion of biofuel production and contributing to energy security, market predictability, and emissions mitigation. This policy justifies by Brazilian history and biofuel production competitive advantages, mainly sugarcane ethanol if compared to U.S. corn ethanol (Gonçalves, 2017; Barbosa, Szklo, & Gurgel, 2022; MME, 2019).

According to Barbosa et al. (2022), Brazilian sugar-energy companies have been crossing a very challenging economic period. Although revenues increased, return margin decreased due to low prices and intense competition, resulting in increasing companies' debts. This led to a merging and acquisitions movement, intensified by economic issues due to the Covid-19 pandemic, besides low R&D investment. Still, according to the authors, deforestation in Brazil could also bring losses to the sugar-energy industry by creating a negative image even though sugarcane production does not occur in an illegally deforested area.

First-generation ethanol (1G ethanol) production from molasses, grains, or starchy is a well-established and mature process. Besides, in Brazil, sugarcane farming can be managed in a complementary way with food production by crop rotation. To enhance even more productivity in the sugar-energy sector, RenovaBio also aims to promote second-generation ethanol (2G ethanol) from sugarcane bagasse, a residue from 1G ethanol and sugar production. Despite still existing several technological and economic challenges to overcome, the development of biorefineries to produce biofuels, such as 2G ethanol, biochemicals and biomaterials has shown promising. Indeed, India is also looking up for 2G ethanol production to boost its mandate of ethanol in the gasoline mix over the last years. (Chandel, et al., 2019; MME, 2019; Barbosa, Szklo, & Gurgel, 2022/ Mookherjee, 2022).

Noticing the low investment level on R&D in last years, the federal government launched a new program in 2021 called "Fuels of the Future", aiming to promote the development of advanced biotechnologies, such as ethanol fuel cells, previously approached. Thus, electromobility, at the same time could be seen as a threat to ethanol as fuel of low emissions vehicles, also could represent an opportunity since ethanol fuel cells gain relevance and market share in the electric fleet (MME, 2021b; Barbosa, Szklo, & Gurgel, 2022).

Table 6 – Sugarcane ethanol SWOT analysis

SWOT	Helpful	Harmful
Internal	**Strengths** ● Large flex fuel fleet; ● Established distribution and commercialization infrastructures; ● 2G ethanol from bagasse; ● Higher productivity compared to US corn ethanol.	**Weaknesses** ● High sector companies debt; ● Low investment returns; ● Low R&D investment.

	Opportunities	Threats
External	• RenovaBio incentives to expand production; • Direct ethanol (Biofuel cell); • Fuels of the Future Program (drop-in solutions); • Biofuel international attractiveness due to BECCS; • Complementarity with food production. • Increase in ethanol mandates in other countries.	• Risks associated with land use change; • Loss of companies' intangible value due to deforestation; • Electromobility deleverage biofuel potential; • Low gasoline prices; • Competition with sugar market.

4. Conclusions

The transition to sustainable societies based on renewable energy sources is a long road on which nations will continue in the coming decades. This road will be paved not only by the multiple technological advances required for its success but, also by the willpower of the international community to act in time and with the intensity required. However, the route on which it will happen is not defined yet. Beyond the various environmental implications of the transition, the priorities defined for the current and future socio-economic issues are paramount. In that sense, disregarding a just transition path that guarantees emerging and affluent countries specific needs and a more equal outcome, can lead to an ethically questionable destination.

Although current social-economic issues, Brazil has the potential to assume a leading role in this effort. When we analyze the six technologies selected, it is clear Brazil can take advantage of its strong potential in the agriculture sector. This grants competitive and comparative advantages on an energy transition pathway based on biofuels. It is important to highlight that the country has a proven track record in promoting a quick and effective transition when implementing ethanol development policies. All the biofuel-related technologies such as ethanol, biofuel cell, SAF, and BECCS can profit from the strengths in this area such as mainly the production capacity and the existing infrastructure. Furthermore, this sector can maintain current jobs and create new ones based on green industry development. Technologically, mainly Biofuel Cell, SAF, and BECCS still require R&D investment to promote commercial feasibility. One aspect to be improved in the biofuel topics is an integrated state strategy addressing the full spectrum of biofuel, and its role in the Brazilian energy transition, including public policies and regulations.

Similar to the ethanol case, Brazil also had in the past a fast industrial development based on government policies and still possesses base industries relevant to the mitigation and adaptation efforts. Hydrogen can have an important role in that regard. Despite, the poor performance as an energy vector and the low technology maturity being a large obstacle to be overcome, hydrogen has potential applications as substitute feedstock in the steel, cement, petrochemical, and fertilizer industries in Brazil. In this context, the National Council of

Energy Policy issued a National Hydrogen Program that defines the hydrogen industry among the priority topics for R&D investment. However, an in-depth and integrated assessment must be prioritized since according to the paper review the intent was not to serve an endogenous demand of Energy Transition but mainly in a commodity export-driven approach.

In the PV arena, it is clear that Brazil possesses very favorable insolation levels that have been translated into a significant expansion in the energy matrix of solar power. It is important also to identify that the country has one of the largest reserves of mineral quartz which could open room for the development of the PV solar panel supply chain). The creation of a local supply chain would benefit the country's renewable expansion, promote industrialization, creation of income and, jobs and support the PV supply chain deconcentrating from China. However, obstacles such as markets and scale of production need to be further analyzed

In an assessment of external factors, Brazil presents an appealing opportunity to lead the Energy Transition as far as biofuel development, exploring technologies such as (i) biofuel cells and customizing the decarbonization of its transportation sector, (ii) boosting BECCS and promoting negative emissions, (iii) developing SAF and positioning itself as a frontrunner in CORSIA agreements and hard to abate sectors, and also (iv) keep expansion of second generation ethanol from bagasse. Challenges intrinsic to biofuels are related to Land Use Change and Climate Change Adaptation and Mitigation. Further studies should be carried out in this sense. Important also to mention that the risk of deforestation of Amazon and other Brazilian biomass must be detached and controlled to have balanced development in the biofuel industry.

Last but not least, structured cooperation among BRICS countries exchanging potentialities in the scope of the Energy Transition could enhance possibilities of win-win solutions via technology transfer partnerships, increase trade among members, and support other emerging economies in the transformation to a lower emission paradigm.

5. Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

Julia Paletta Crespo thanks to financial support from the Human Resources Program of the National Agency of Petroleum, Natural Gas, and Biofuels - PRH-41/ANP (in Portuguese), supported with funds from the investment of oil companies qualified in the R&DI Clause of ANP Resolution 50/2015.

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