Carbon Reduction Potential and its Related Land Requirement: Analysis on Energy Transition Pathways for the Brazilian Steelmaking

Jhonathan Fernandes Torres de Souza[1] and Sergio Pacca[2]

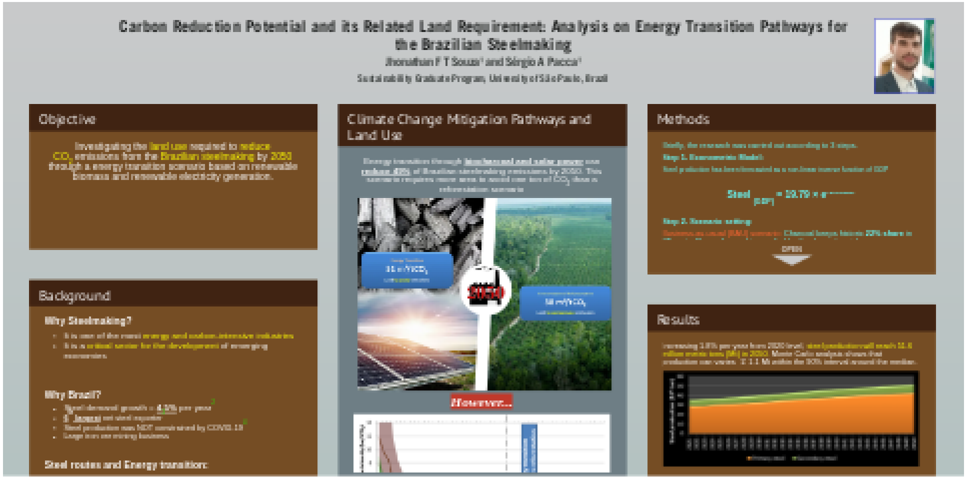
[1]Universidade de São Paulo
[2]University of São Paulo (USP)

November 23, 2022

Abstract

Steelmaking is a key-sector for development; it is also one of the most energy and CO_2 intensive industries. Brazilian steelmaking was responsible for 44.3 million metric tons of CO_2 emissions and 40% of its output supported the international steel demand in 2018. Then, there is a need to harmonize the increasing steel demand with low carbon energy alternatives towards sustainable development. Here, we forecast scenarios until 2050 to analyze the CO_2 reduction potential through energy transitions in two production routes of the Brazilian steelmaking: for primary steel, the increase of renewable charcoal use in blast furnaces; and for secondary steel, whose direct emission is relatively low but it is highly power intensive, the use of on-site photovoltaic (PV) energy to meet the power demand. Renewable energy sources for electricity play a particularly relevant role as power demand increases 69% with the substitution of charcoal for coke. The analysis has been supported by econometric models and emission factors from the IPCC GHG inventory guidelines for direct and indirect emissions. Results have shown that steel production will increase 1.8% per year from 2020 levels and will yield $77MtCO_2$ in 2050. The Charcoal+PV scenario can mitigate 49% of such emissions. The land-intensity to enable such scenario is $51m^2$ per avoided tCO_2 for the entire period. Alternatively, if steel sector's emissions were compensated by native reforestation, this value decreases to $38m^2/tCO_2$. However, according to the uncertainty analysis, reforestation presents a higher land-intensity than charcoal+PV scenario in 31% of the Monte Carlo simulations. In addition, other issues affect suitability of the scenarios and must be discussed: the benefit-cost of bioenergy versus costs of conservational reforestation; ancillary benefits of standing forests such as biodiversity improvement. Moreover, considering the carbon cycle, charcoal is sustainable far beyond the analyzed period, whereas new areas will be needed to stock carbon in conservational reforestation projects. The findings of this study can assist governmental and private decision-makers to elaborate policies for more plausible pathways to confront climate change and guarantee economic, social, and environmental development.

Carbon Reduction Potential and its Related Land Requirement: Analysis on Energy Transition Pathways for the Brazilian Steelmaking



Jhonathan F T Souza[1] and Sérgio A Pacca[1]

Sustainability Graduate Program, University of São Paulo, Brazil

PRESENTED AT:

OBJECTIVE

Investigating the land use required to reduce CO_2 emissions from the Brazilian steelmaking by 2050 through a energy transition scenario based on renewable biomass and renewable electricity generation.

BACKGROUND

Why Steelmaking?[1]

- It is one of the most energy and carbon-intensive industries
- It is a critical sector for the development of emerging economies

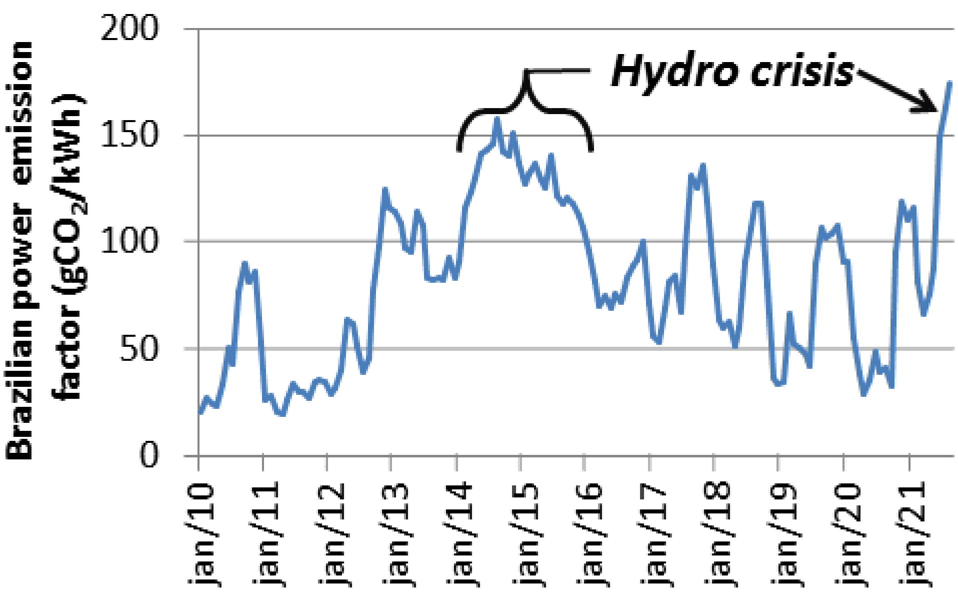
Why Brazil?

- Steel demand growth = **4.5%** per year[2]
- **6th largest** net steel exporter[3]
- Steel production was NOT constrained by COVID-19[4]
- Large iron ore mining business

Steel routes and Energy transition:

- **Primary Steel:** obtained from iron ore. Massive emissions come from the use of fossil coal coke in Blast Furnaces (BF).
- **Secondary Steel: obtained** from end-of-life scrap. The main energy carrier demanded is power for the Electric Arc Furnaces (EAF).

Although the non-use of coke affords low direct emissions through the EAF route, the high power intensity will be a concern as Brazilian grid emission factor is predicted to increase with climate change



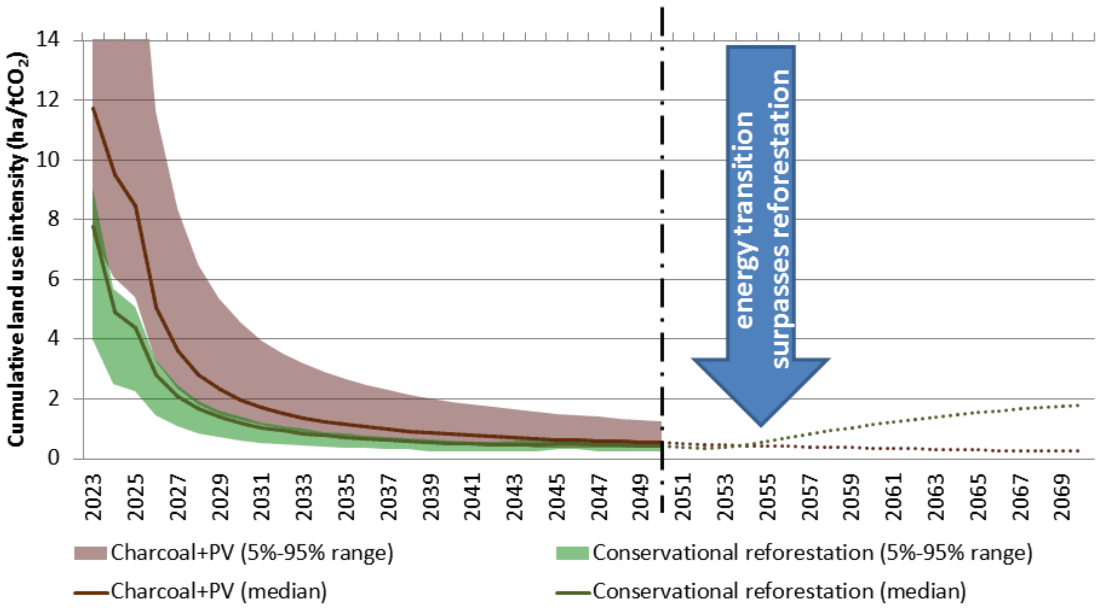
Source: Brazil, 2021[5]

Meanwhile, **biocharcoal** stands out as one of the best options to replace coke in BF[6]. On the one hand, Brazil is the world's largest biocharcoal producer, whose major destination is steelmaking. On the other hand, two main barriers that affect a broad adoption of biocharcoal are the production costs compared to the coke opetion and the area required to grow eucalyptus.

CLIMATE CHANGE MITIGATION PATHWAYS AND LAND USE

Energy transition through **biocharcoal and solar power** can **reduce 49%** of Brazilian steelmaking emissions by 2050. This scenario requires more area to avoid one ton of CO_2 than a reforestation scenario

However...



In long-run, the energy transition scenario is sustainable as new land is only required for marginal steelmaking growth, whereas land to reforest will be continuously needed to uptake carbon dixoxide.

METHODS

Briefly, the research was carried out according to 3 steps.

Step 1- Econometric Model:

Steel production has been forecasted as a non-linear inverse function of GDP

$$\mathbf{Steel}_{(GDP)} = 19.79 \times e^{(-649.5/GDP)}$$

Step 2- Scenario setting:

Business-as-usual (BAU) scenario: Charcoal keeps historic **22% share** in BF route. Power demand is supplied by the domestic grid.

Alternative scenarios:

- Energy Transition (ET) Scenario: The share of charcoal i**ncreases to 100% until 2025**, as well as on-site solar power generation, keeping this level until 2050.
- Conservational Reforestation (CR) Scenario: ALL steelmaking CO_2 emissions are uptaken by native reforestation growth. The penetration is the same as the ET Scenario.

Step 3- Uncertainty analysis:

Based on Monte Carlo Method, a set of variables have been randomized within a normal probability distribution function:

- GDP annual growth rate
- Carbon stock capacity of tropical forest
- Solar radiation potential
- Eucalyptus productivity for biocharcoal production

10,000 simulations were run to calculate statistical positions

Primary data sources:

Steel production series: Brazil Steel Institute (IABR)[4]

GDP series: World Bank[7]

GDP forecast: National Energy Plan- Brazilian Ministry of Mines and Energy[8]

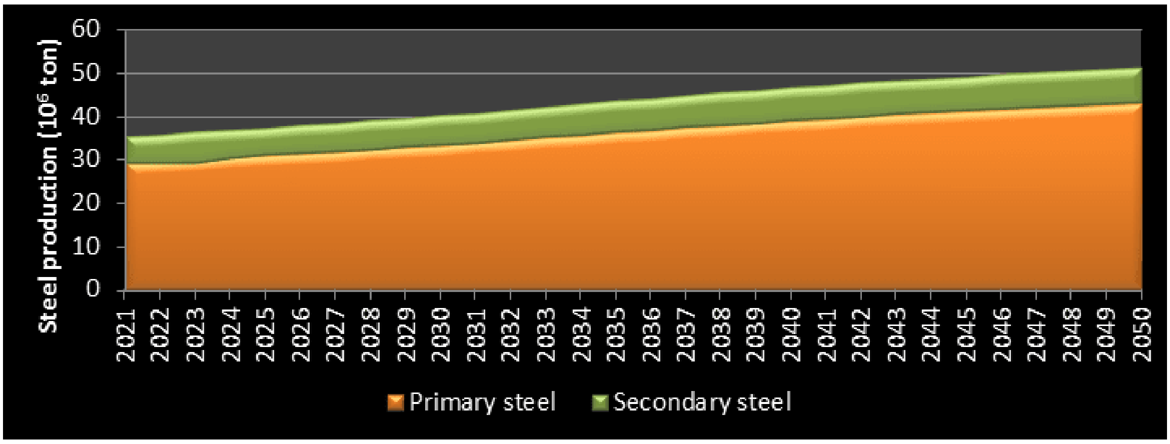
Energy consumption and emission factors: IPCC 2006 guidelines for National GHG Inventories (Vol. 2 and 3)[9]

Solar radiation potential: Laboratory of Modeling and Studies on Renewable Energy Resources (LABREN)[10]

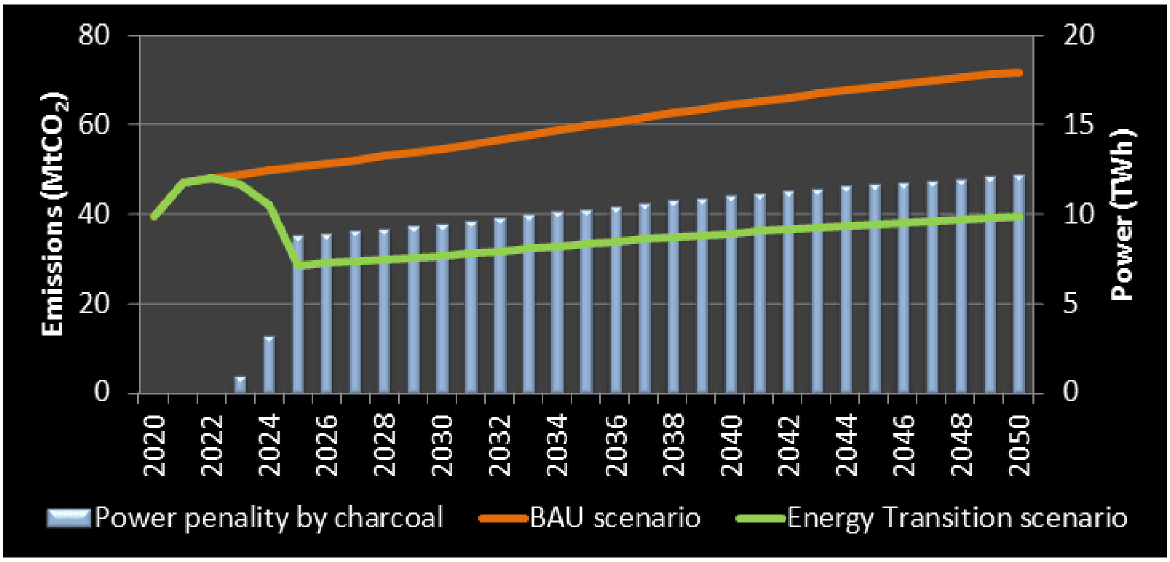
Reforestation carbon stock: IPCC 2006 guidelines for National GHG Inventories (Vol. 4)[9]

RESULTS

Increasing 1.8% per year from 2020 level, steel production will reach 51.6 million metric tons (Mt) in 2050. Monte Carlo analysis shows that production can varies ∓ 1.1 Mt within the 90% interval around the median.

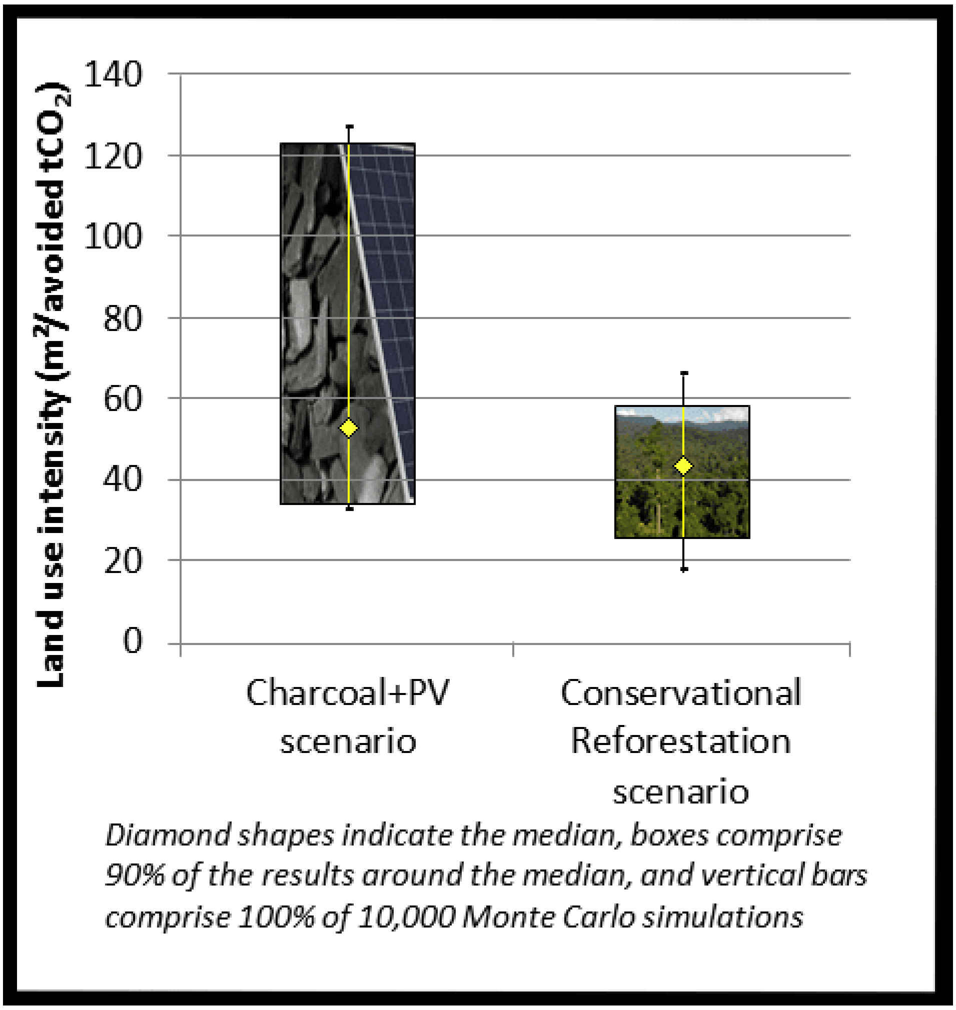


In the BAU scenario, emissions follow steel production, totalizing 1.8 $GtCO_2$ emitted from 2020 to 2050. With the ET scenario, 39% of such emissions can be avoided.



Since charcoal-based route does not usually utilize residual gases, BF net power demand increases around 70%. Then, solar and other renewable electricity sources are a important complementar strategy given such power penality.

Regarding the land requirement, 3.7 million hectares (Mha) would be needed to implement ET scenario. In the CR scenario, this value is 6.2 Mha, but as CR scenario solves all steelmaking emissions after 2025, the land use intensity for this scenario is $38m^2/tCO_2$ against $51m^2/tCO_2$ for ET scenario.



However, according to the uncertainty analysis, reforestation presents a higher land-intensity than charcoal+PV scenario in 31% of the Monte Carlo simulations. Moreover, going beyond the scenario timeframe (as seen in the central panel), ET scenario is less land-intensive than CR scenario after 2055.

Apart from the findings, other issues weigh on the choice for a more sustainable pathway. Some of them are (a) the benefit-cost of bioenergy versus costs of conservational reforestation and (b) the ancillary benefits of standing forests, such as ecosystem services. Therefore, the more plausive pathway would be a set with both scenarios, even more that only ET scenario can not avoid all steelmaking emissions. Anyway, the higher the share of ET scenario, the lower the land use intensity, specially if steelmaking will present high growth rates for the next years.

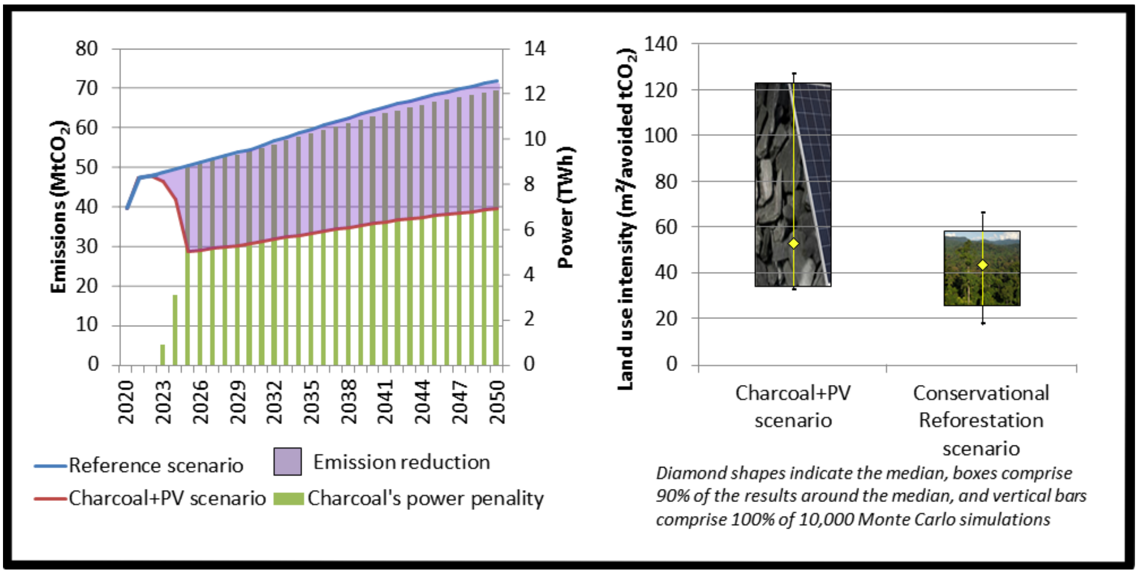
The approach used in this work can be applied to other industries and other countries in the developing world.

***Acknowledgement**:*

This study is supported by **São Paulo Research Foundation (FAPESP), grant 2018/23439-1**

ABSTRACT

Steelmaking is a key-sector for development; it is also one of the most energy and CO_2 intensive industries. Brazilian steelmaking was responsible for 44.3 million metric tons of CO_2 emissions and 40% of its output supported the international steel demand in 2018. Then, there is a need to harmonize the increasing steel demand with low carbon energy alternatives towards sustainable development. Here, we forecast scenarios until 2050 to analyze the CO_2 reduction potential through energy transitions in two production routes of the Brazilian steelmaking: for primary steel, the increase of renewable charcoal use in blast furnaces; and for secondary steel, whose direct emission is relatively low but it is highly power intensive, the use of on-site photovoltaic (PV) energy to meet the power demand. Renewable energy sources for electricity play a particularly relevant role as power demand increases 69% with the substitution of charcoal for coke. The analysis has been supported by econometric models and emission factors from the IPCC GHG inventory guidelines for direct and indirect emissions. Results have shown that steel production will increase 1.8% per year from 2020 levels and will yield 77MtCO_2 in 2050. The Charcoal+PV scenario can mitigate 49% of such emissions. The land-intensity to enable such scenario is 51m² per avoided tCO_2 for the entire period. Alternatively, if steel sector's emissions were compensated by native reforestation, this value decreases to 38m²/tCO_2. However, according to the uncertainty analysis, reforestation presents a higher land-intensity than charcoal+PV scenario in 31% of the Monte Carlo simulations. In addition, other issues affect suitability of the scenarios and must be discussed: the benefit-cost of bioenergy versus costs of conservational reforestation; ancillary benefits of standing forests such as biodiversity improvement. Moreover, considering the carbon cycle, charcoal is sustainable far beyond the analyzed period, whereas new areas will be needed to stock carbon in conservational reforestation projects. The findings of this study can assist governmental and private decision-makers to elaborate policies for more plausible pathways to confront climate change and guarantee economic, social, and environmental development.



(https://agu.confex.com/data/abstract/agu/fm21/4/8/Paper_850584_abstract_789693_0.png)

REFERENCES

[1]FISCHEDICK, M. et al. (2014). Industry. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge (UK) e New York (USA): Cambridge University Press, 2014. p. 739–810.

[2]Brazilian Ministry of Industry, Foreign Trade and Services, and Brazil Steel Institute (2020). Consumo aparente de produtos siderúrgicos [excel file requested by email].

[3]World Steel Association (2019). World Steel in Figures 2019. <https://www.worldsteel.org/media-centre/press-releases/2019/world-steel-in-figures-2019.html>

[4]Brazil Steel Institute (2020). “Estatística De Desempenho.” <https://institutoacobrasil.net.br/site/estatistica-de-desempenho/>.

[5]Brazilian Ministry of Science, Technology, Innovation and Communication (2021). “Fator Médio Inventários Corporativos.” https://www.mctic.gov.br/mctic/opencms/ciencia/SEPED/clima/textogeral/emissao_corporativos.html.

[6]Suopajarvi, H., Kemppainen, A., Haapakangas, J., Fabritius, T (2017). Extensive review of the opportunities to use biomass-based fuels in iron and steelmaking processes. J. Clean. Prod. 148, 709–734. <https://doi.org/10.1016/j.jclepro.2017.02.029>.

[7]WORLD BANK (2021). GDP per capita, PPP (constant 2017 international $) - Brazil. <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD?locations=BR>

[8]Energy Research Office, and Brazilian Ministry of Mines and Energy (2018). Cenários Econômicos Para o PNE 2050. EPE, Rio de Janeiro. <https://www.epe.gov.br/sitespt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-201/Cen´ariosEconˆomicos.pdf>.

[9]Intergovernmental Panel on Clinate Change (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Hayama: IGES.

[10]LABREN (2017). Atlas Brasileiro de Energia Solar - 2ª Edição <https://agu2021fallmeeting-agu.ipostersessions.com/default.aspx?s=83-EE-17-18-02-2C-B8-64-28-81-E5-DE-FE-C1-2C-8B>