Development of Database Management System (DBMS) for Sustainable Aviation Biofuel in Brazil

Case study: HEFA pathway / macaw palm

Authors: Arnaldo Walter, Joaquim E. A. Seabra, Jansle Vieira Rocha, Marjorie Guarenghi, Nathália Vieira, Desirèe Dalmane (Unicamp), João L. Santos (GeoMeridium)

http://dx.doi.org/10.17632/5498jdrm87.1

July 2020

Executive summary

- In this project the case studies were developed with the aim of illustrating the use of the information available in the platform database to evaluate the potential of SAF (sustainable aviation fuel) production in Brazil. It is not possible to draw definitive conclusions based on the results obtained, but an effort has been made to make the studies as comprehensive as possible.
- The case study reported here addresses the production of SAF through the HEFA-SPK route, considering macaw palm (macaúba) oil as feedstock. Macaúba is a traditional palm in the Americas, but knowledge related to its commercial production is still scarce.
- The self-dedicated production of macaw palm oil was assessed in ten different sites and it was considered the possible production of SAF in three oil refineries (two in southeast – REVAP and REGAP – and one in northeast – RNEST). It was assumed self-dedicated production of the vegetable oil. Five different industrial capacities of SAF production were considered.
- The estimated minimum selling price (MSP) varies between 660-1069 €.t^{-1} of SAF (or from 15.4 to 25.0 €.GJ^{-1}), depending on aspects such as the production site of the macaw palm and the scale of SAF's industrial production plant.
- The reported case study shows that the production of SAF from macaw palm oil could be feasible in Brazil in mid- to long-term. For the best cases from an economic point of view, the estimated MSP show feasibility vis-à-vis current fossil jet-fuel prices. However, feasibility would depend on some factors, such as oil yield, reduction of transportation distances and on taking advantage of the scale effects in the industrial side.

Summary

- About the pathway;
- About macaw palm (macauba);
- Macaw palm in Brazil;
- Case studied;
- Methodology;
- Macaw suitability (procedure, validation & results);
- Macaw productivity – oil yield;
- Production costs;
- Results of the case study, analysis & comparisons;
- Conclusions;
- References;
- Supplementary Material.

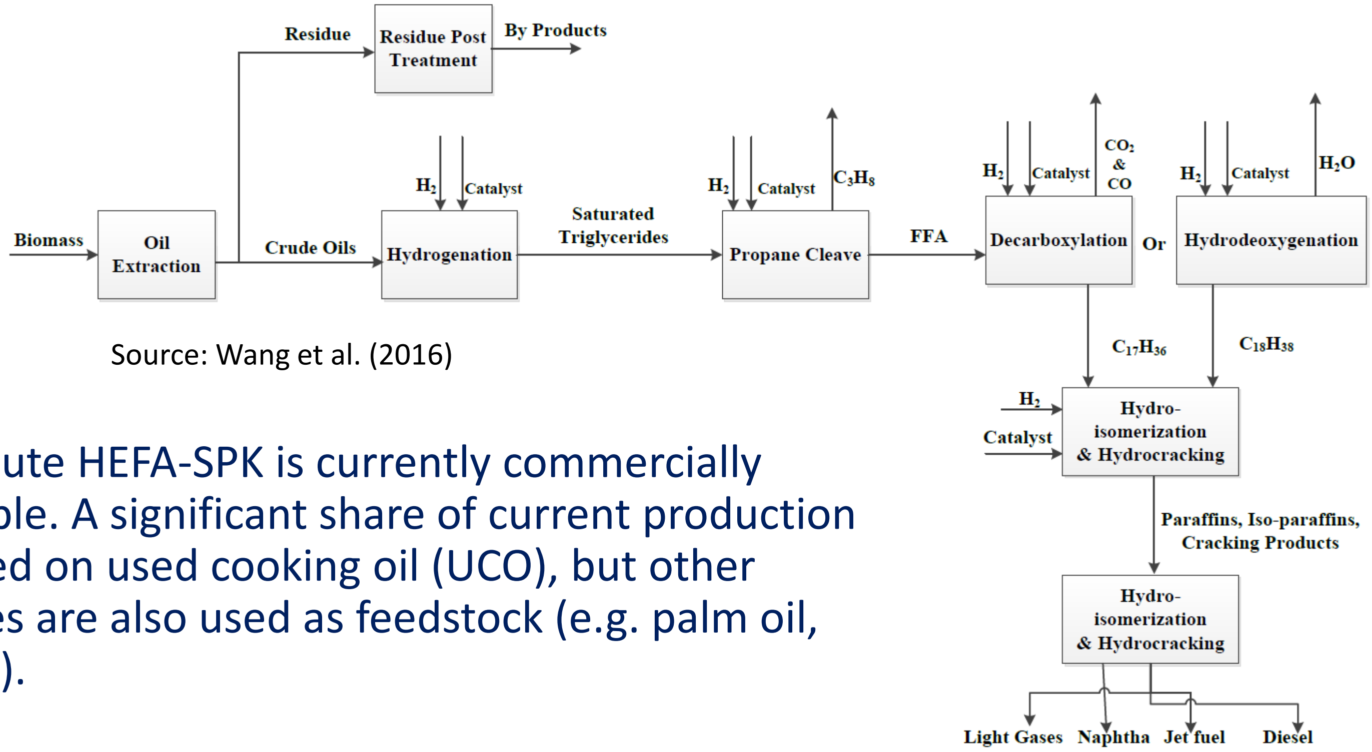
About the pathway (1)

- The route HEFA-SPK was approved by ASTM D7566 in 2011.
- Vegetable oils, waste oils or fats can be refined into SAF (Sustainable Aviation Fuels) through a process that uses hydrogen (hydrogenation). First, the oxygen is removed by hydride-oxygenation. Next the straight paraffinic molecules are cracked and isomerized to jet fuel chain length (SkyNRG, 2020).
- Oil-based feedstocks considered in the database are those mainly available in Brazil and/or with a good potential in short to mid-term: soybean oil, palm oil, macaw oil (macauba) and tallow.
- The reported case study is based on the oil of macaw palm (macauba).

Conversion processes approved by ASTM International

Conversion process	Abbreviation	Possible feedstocks	Blending ratio by volume	Commercialization proposals
Synthesized paraffinic kerosene produced from hydro-processed esters and fatty acids	HEFA-SPK	Bio-oils, animal fat, recycled oils	50%	World Energy, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC

Source: adapted from ICAO (2018) and ASTM (2020)

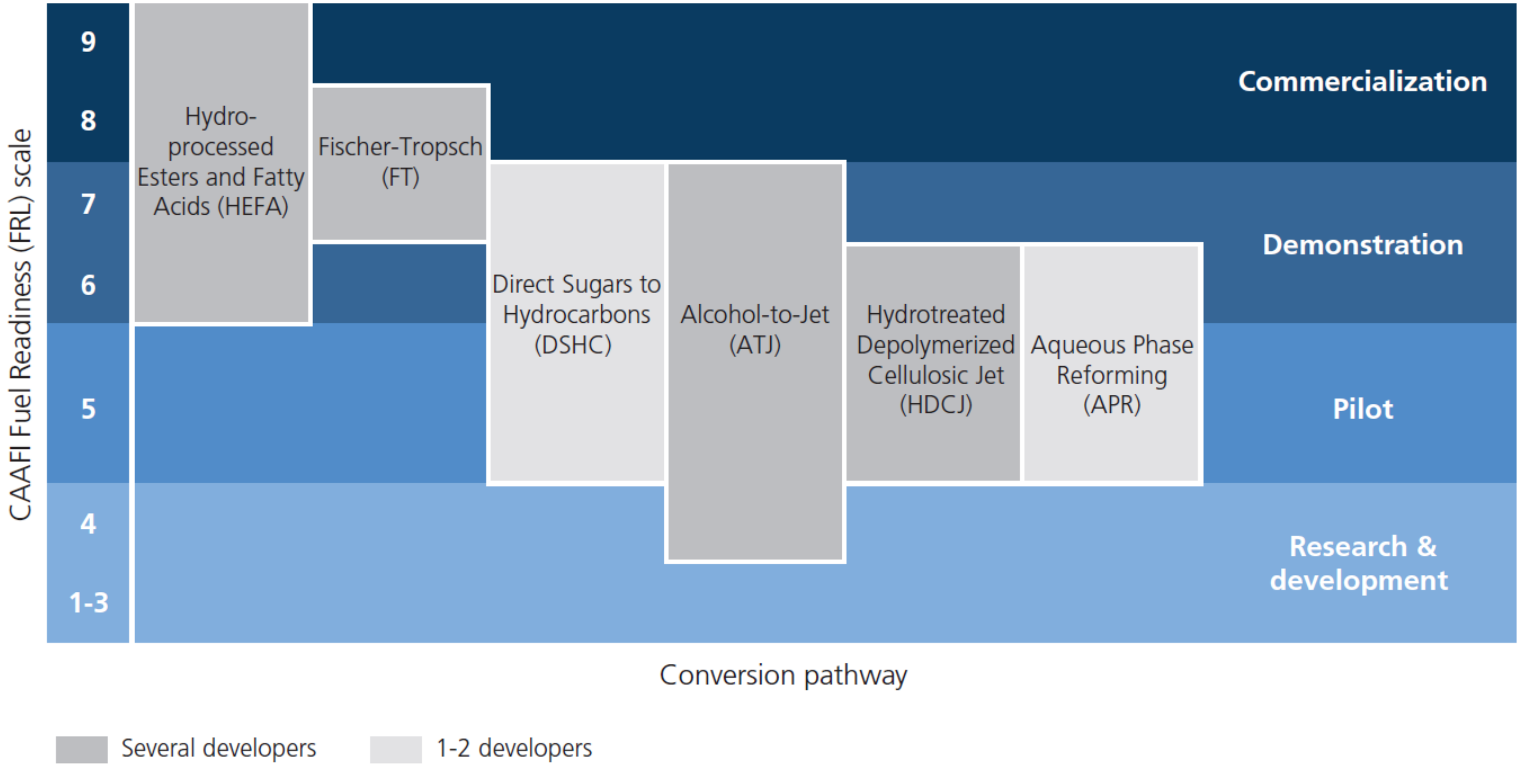


Source: Wang et al. (2016)

- The route HEFA-SPK is currently commercially available. A significant share of current production is based on used cooking oil (UCO), but other sources are also used as feedstock (e.g. palm oil, soy oil).

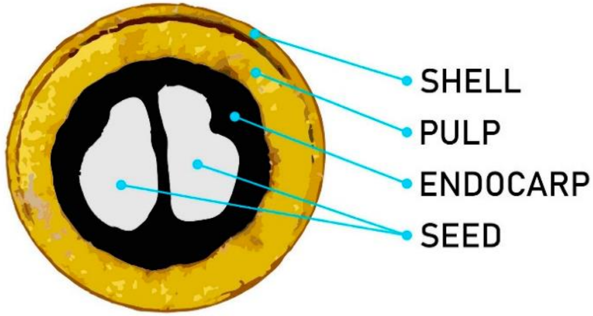
About the pathway (2)

- The figure, extracted from de Jong et al. (2017) is a representation of CAAFI's (Commercial Aviation Alternative Fuels Initiative) Fuel Readiness Level Scale (FRL). It is based on NASA's Technology Readiness Level (TRL) scale and is intended to provide a classification to describe the progress of a conversion pathway towards commercialization. Key milestones include proof of concept (FRL 3), scaling from laboratory to pilot (FRL 5), certification by the American Society for Testing and Materials (ASTM) (FRL 7), and full scale plant operational (FRL 9).



- The figure is not exhaustive, as more pathways have being considered for the production of SAF.
- A similar analysis is provided by Prussi et al. (2019). For the HEFA-SPK route, the authors present the Readiness Technology Level (RTL) at 9, as defined by the EU HORIZON Work Program 2016-2017 (2019), and the FRL at 9, defined as mentioned above. Thus, in both cases, the highest score is assumed.

About macauba (macaw palm) (1)



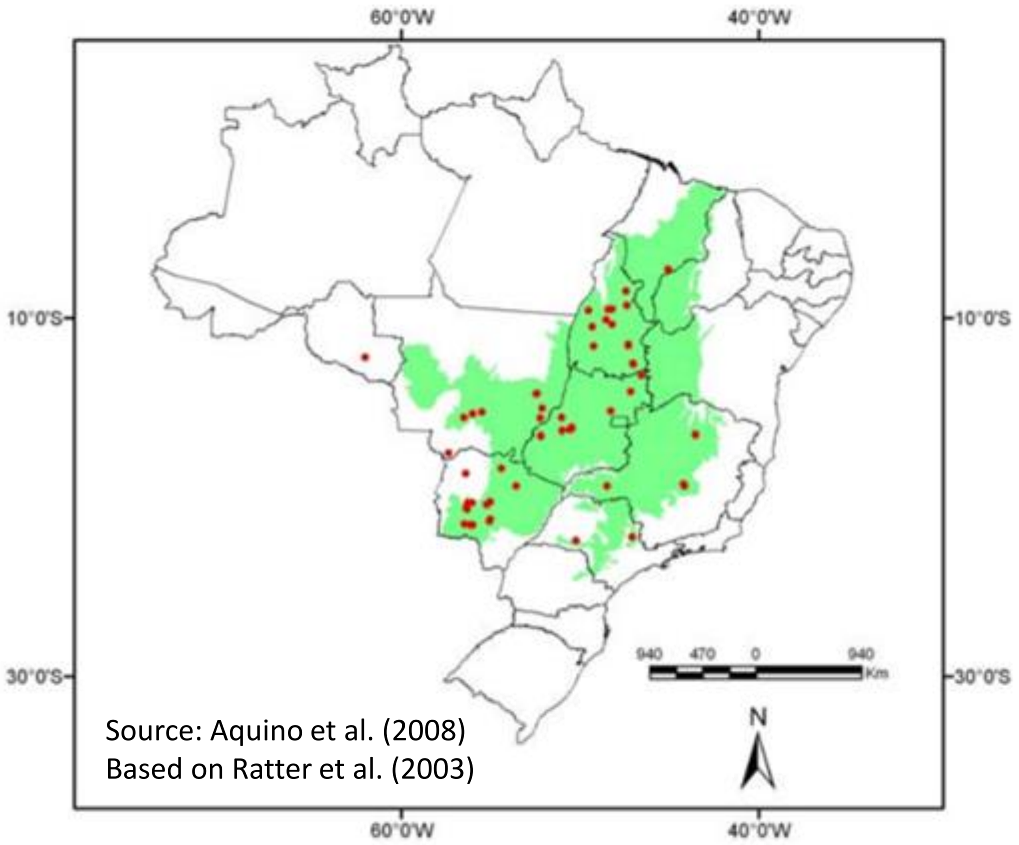
Sources: from left to right, Portal Macauba (2020), EMBRAPA (2020), Calvani et al. (2020).

- The most common scientific name for macauba is *Acrocomia aculeata* (Jacq.) Lodd. ex Mart (MDA, 2014) (it is a palm tree of the genus *Acrocomia*). Another common designation is macaw palm (Machado et al., 2016).
- Its natural occurrence is in semi-deciduous forests or savannas, as well as in anthropized areas, such as in areas occupied by pastures (Evaristo et al., 2016). Colombo et al. (2018) cite records of naturally occurring in dry areas, from Mexico to northern Argentina.
- According to Lima et al. (2018), there are few species studies and doubts about taxonomic classification. But there are indications of high genetic diversity and natural populations with large phenotypic variability.

About macauba (macaw palm) (2)

- Popular uses of macauba include direct use as food, in the preparation of condiments, in lighting (use of oil), medicinal use of pulp and fruit oil, in feeding animals, as mosquito repellent, and in the manufacture of soaps (Colombo et al., 2018). More recently, due to the high oil productivity, it has been evaluated as a raw material for the production of biodiesel and bio-jet fuels (Machado et al., 2016).
- Oil can be produced from the mesocarp (pulp) or from the almonds (seeds). Due to the higher quality, oil from the almonds (i.e. from the endosperm) is used in the pharmaceutical and on the cosmetic industry, while the oil from the pulp can be used for producing fuels (biodiesel or bio-jet fuels) (Colombo et al., 2018).
- According to REMAPE (Macauba Research Network) (http://www.macauba.ufv.br/), there is commercial exploitation of macauba in Brazil and Paraguay, for the production of food (e.g. flour, ice cream, oils) and in pharmo-chemistry (e.g. production of cosmetics and soaps). When vegetable oil is produced, there is also the production of co-products such as meal (i.e. pulp and almond residues after pressing) and endocarp, which can be used to produce charcoal. REMAPE is based on the Federal University of Viçosa, in Minas Gerais, but it is a partnership of the University with Research Institutes and companies.

Macauba in Brazil



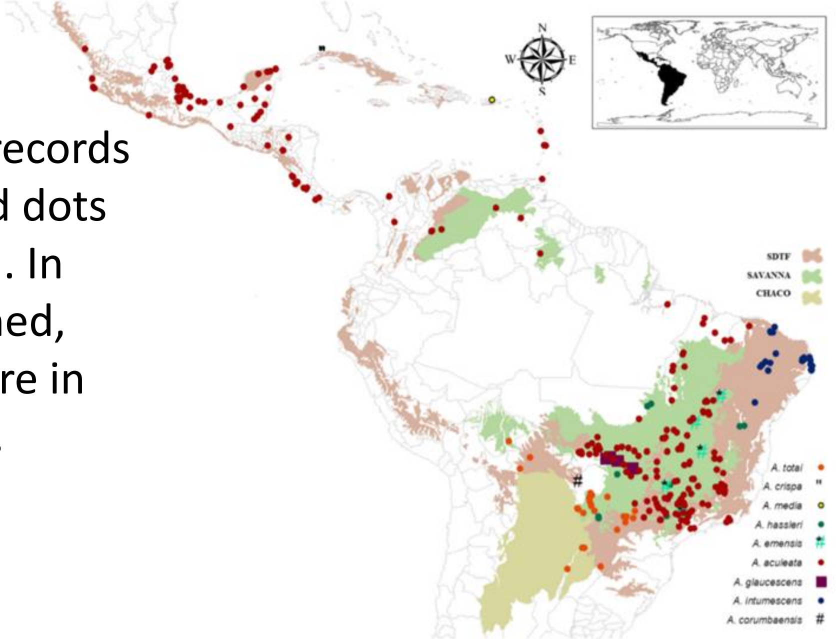
Source: Aquino et al. (2008)
Based on Ratter et al. (2003)

- In Brazil, macauba naturally occurs mainly in Cerrado and in semi-deciduous forests. There are naturally occurring records of macauba in the Northeast region (e.g. Bahia, Piauí and Maranhão), Centre-West region (Goiás, Mato Grosso do Sul and Mato Grosso) and in the Southeast (e.g. Minas Gerais, São Paulo and Rio de Janeiro), besides Tocantins (in the North region) (Lima et al., 2018).

- The figure above, as an illustration, shows the location of 53 naturally occurring records of macauba in the Cerrado biome (area marked green in the figure).
- The IBGE recorded a small commercial production of the macaw fruit in 2017 (133 tonnes). Only four states covered most of the production: MG (41%), CE (23%), MT (11%) and TO (8%).

- The figure to the side shows records of naturally occurring (the red dots in the figure) in Latin America. In the Brazilian case, as mentioned, the majority of occurrences are in the Cerrado (savanna) biome.

Source: Lima et al. (2018)



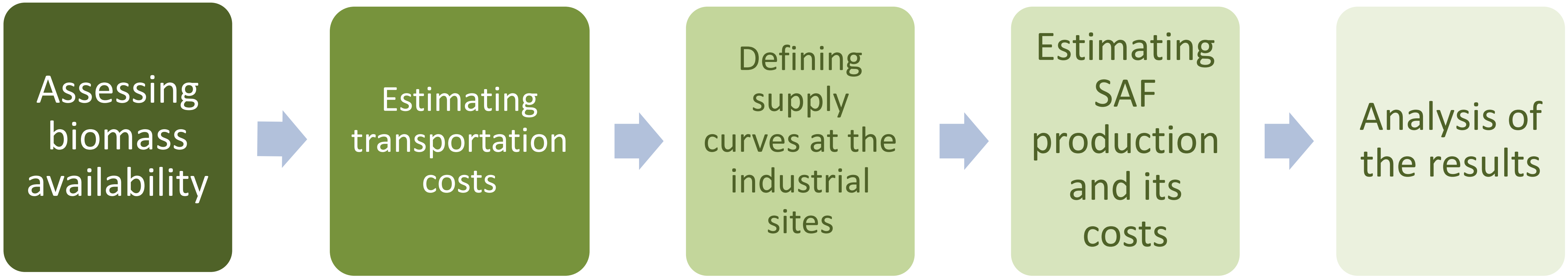
Ongoing projects for commercial production

- In Colombo et al. (2018) it is mentioned that in 2017 there was, in Brazil, three initiatives for the commercial production of macauba. At the time, Entaban Brasil was starting production in an area of 600 hectares, while Soleá Brasil had 1,000 hectares planted, with the expectation of reaching 5,000 hectares in 2022. The third initiative was from the Inocas project, which then planted 2,000 hectares in Patos de Minas, MG. According to the authors, the production could be destined to the production of biodiesel or bio-jet fuels.
- The Entaban Ecoenergéticas do Brasil is a company of the Spanish group Entaban. The project is in Lima Duarte, Minas Gerais. It started with the planting of 1.5 million macauba seedlings in a nursery, in partnership with the Federal University of Viçosa (UFV) (researchers developed the plant's germination technique in the laboratory). In principle, the objective is the production of biodiesel.
- Soleá Brasil Óleos Vegetais Ltda is planting macauba in João Pinheiro, Minas Gerais. On the company's website (https://www.soleabrasil.com.br/) the indication is that the objective is the production of special oils, without explicit mention of bio-jet fuels.
- As for Inocas, the company's website (http://www.inocas.com/) mentions bio-jet fuels production and a partnership with Lufthansa. European funding and the participation of universities (including Leuphana University in Lüneburg, Germany) are cited.

Cases studied

- The case study corresponds to the production of SAF through the route HEFA-SPK, from macaw palm oil, considering self-dedicated plantations.
- The SAF production could be at three oil refineries: (1) at REVAP, in São José dos Campos (the largest producer of fossil jet fuels in Brazil, which is connected through a pipeline with the most important international airport in Brazil – Cumbica); (2) at REGAP, in Betim (close to Belo Horizonte), or (3) at RNEST (an oil refinery under construction, located nearby Recife, in Northeast Brazil).
- Macaw production would be in three different states (Minas Gerais, Goiás and Tocantins), and oil extraction in 10 municipalities in these states (five in Minas Gerais, three in Goiás and two in Tocantins). Reasons for these assumptions are further presented.
- As long as the availability of macauba oil is sufficient, five industrial capacities were considered in order to assess the feasibility. The studies include supply from specific sites, and also the combined supply from all sites assessed here.

Methodology: general procedure



Scheme indicating the main activities in the process of evaluating the potential and economic viability of SAFs, using the platform database.

Methodology: …assessing biomass availability

Assessing biomass availability → Estimating transportation costs → Defining supply curves at the industrial sites → Estimating bio-jet fuel production and its costs → Analysis of the results

- Suitability of macauba;
- Areas available and where production is desirable;
- Potential yields based on literature review;
- Estimated production costs;
- Transport to the oil extraction units;
- Estimating oil costs at the extraction units.

Biomass available due to self dedicated production

Methodology … assessing supply curves at the industrial sites

Assessing biomass availability → **Estimating transportation costs** → **Defining supply curves at the industrial sites** → Estimating bio-jet fuel production and its costs → Analysis of the results

Macaw oil would be transported from the processing units to pre-defined oil refineries, by truck

→

Supply curves of macaw oil are set in each industrial site, considering different SAF production capacities

Methodology … assessing costs and analysis of the results

Assessing biomass availability → Estimating transportation costs → Defining supply curves at the industrial sites → Estimating SAF production and its costs → Analysis of the results

Technical parameters and cost figures have been taken from the literature; costs were corrected to estimate values in 2018 (even for the n^{th} plant)

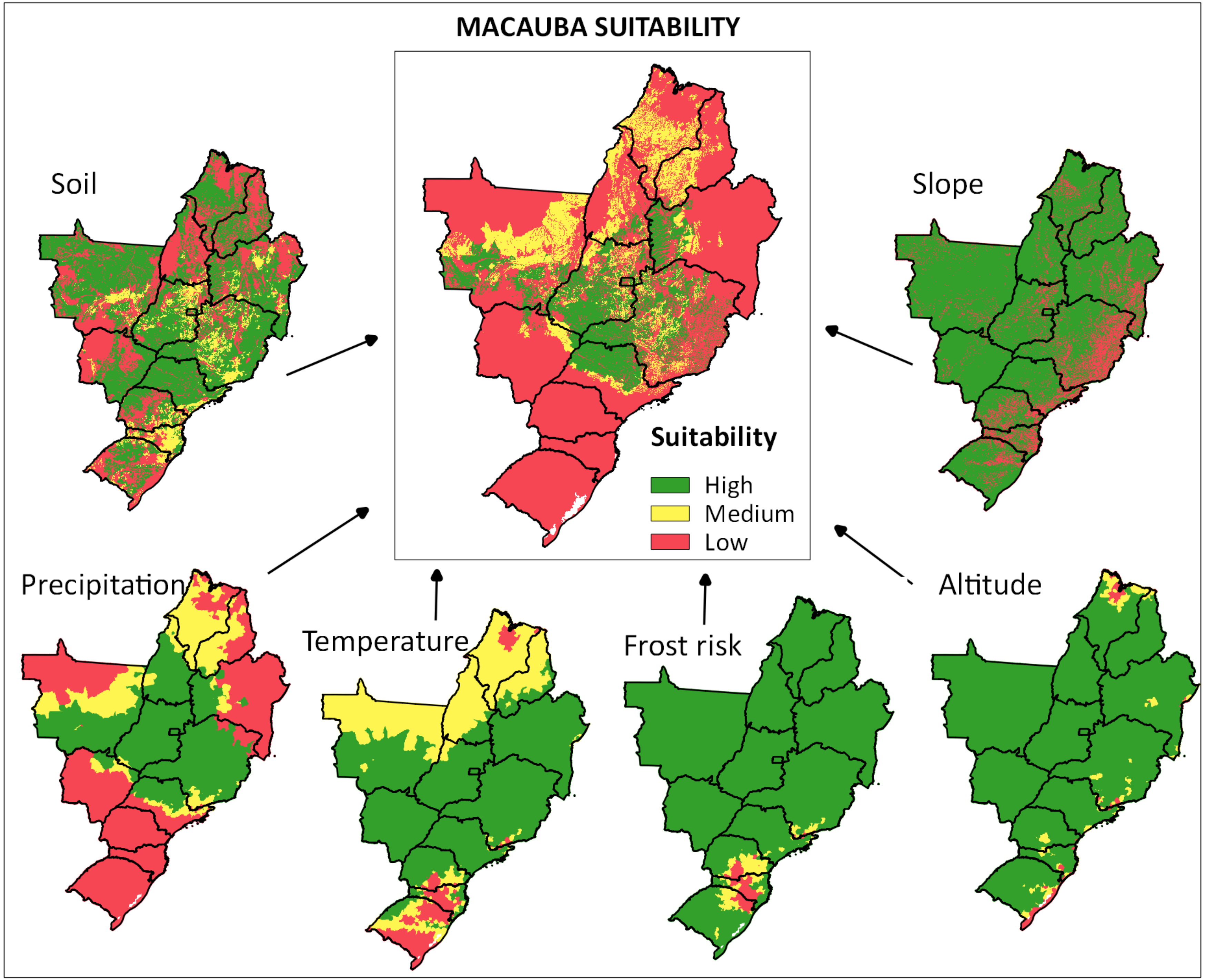
→

Analysis of the results based on Minimum Selling Prices (MSP), comparing with those presented in the literature, and actual fossil kerosene prices, considering cost reduction opportunities and trends, etc.

Macaw suitability (1)

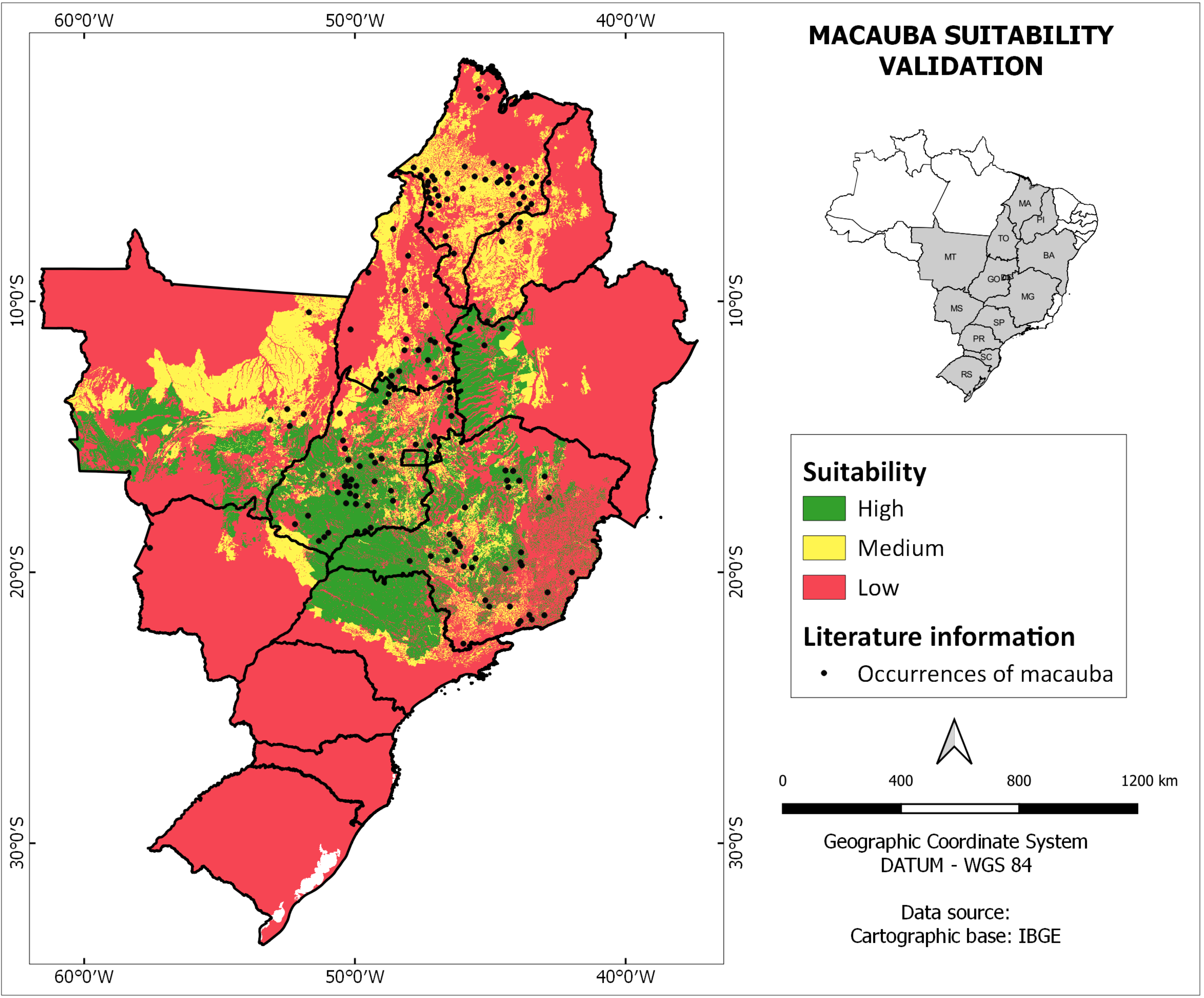
- As there is still insufficient knowledge about macauba, well-established information about its edaphoclimatic suitability was not found. In this sense, the procedure used here is based on parameters of the sites where the natural occurrence of the palm was verified. The simple logic is that it would be possible to make commercial production feasible in places similar to where natural occurrences are observed.
- Thus, climatic parameters were compiled for the municipalities indicated in the literature. Details are presented as supplementary material.
- Soil quality was also considered and the same classification used for other crops (in this project) was applied. Considering the objective of enabling a certain degree of mechanization, the slope of the terrain is also a parameter considered (<13%).
- All parameters were classified into three groups (e.g. suitable-not suitable; good-bad), except slope and frost risk. The high potential suitability was defined for the condition in which the best classification was achieved for all parameters. “Low suitability” does not necessarily mean that production would be impossible.

Suitability (2)



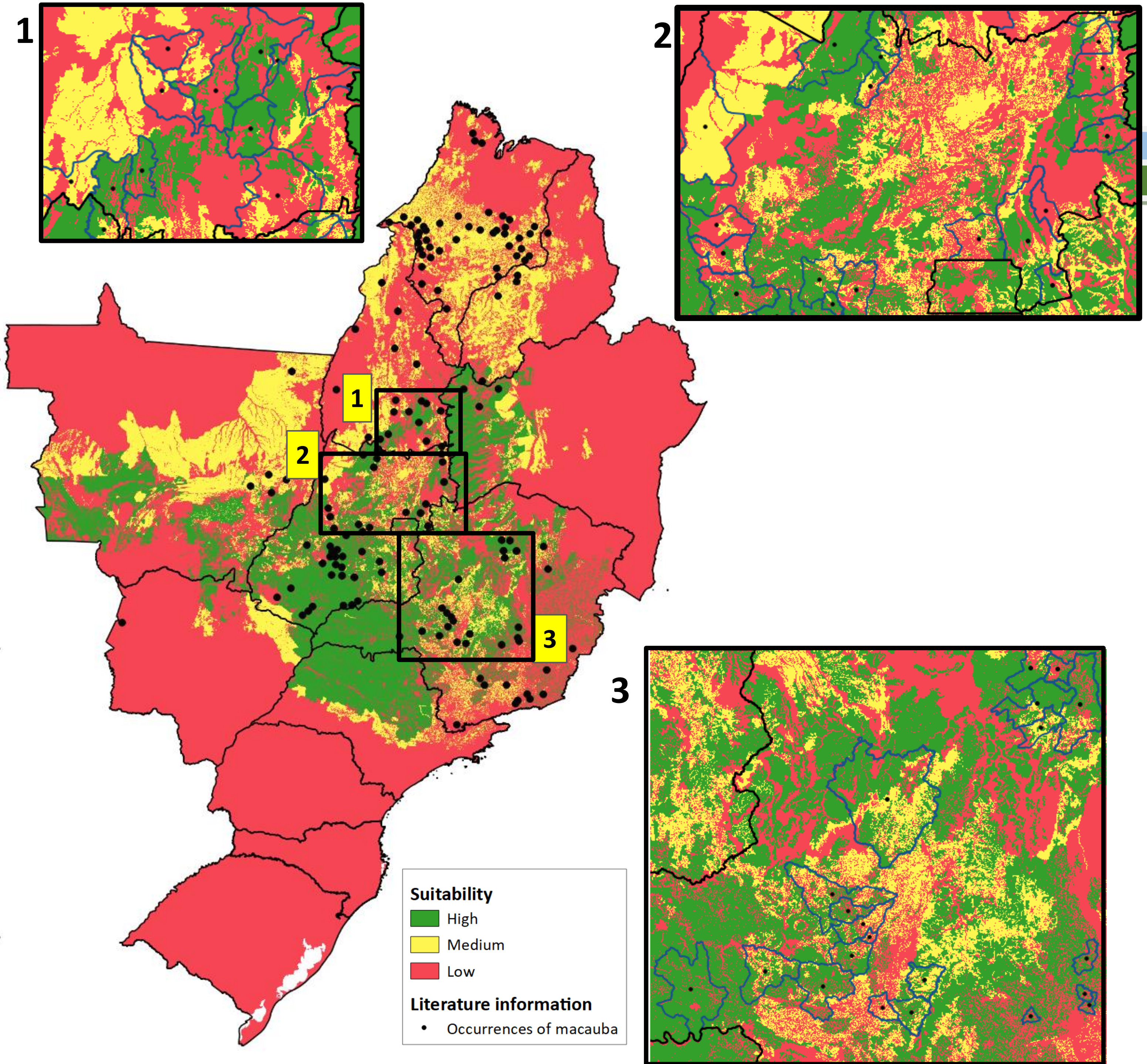
- It can be seen that rainfall and soil are the most restrictive parameters, while frost risk and altitude have a small impact on the final results.
- The resulting suitability map (i.e. for high and medium suitability) is pretty much coincident with the Cerrado biome.

Suitability (3)



- The validation procedure is simply derived from adding the records of the natural existence of macaw palm to the suitability map.
- Due to the less permissive criteria adopted, some records are in regions classified as “medium suitability”. And due to the resolution of the soil map, some records are plotted (or seem to be plotted) in areas classified as "low suitability".

Suitability (4)

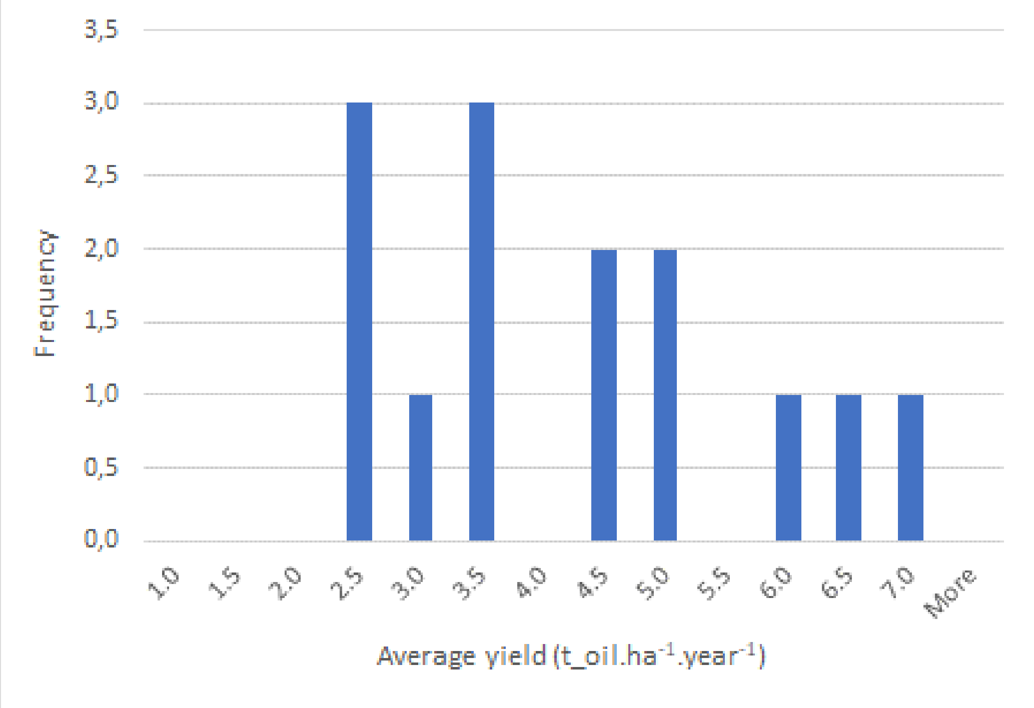


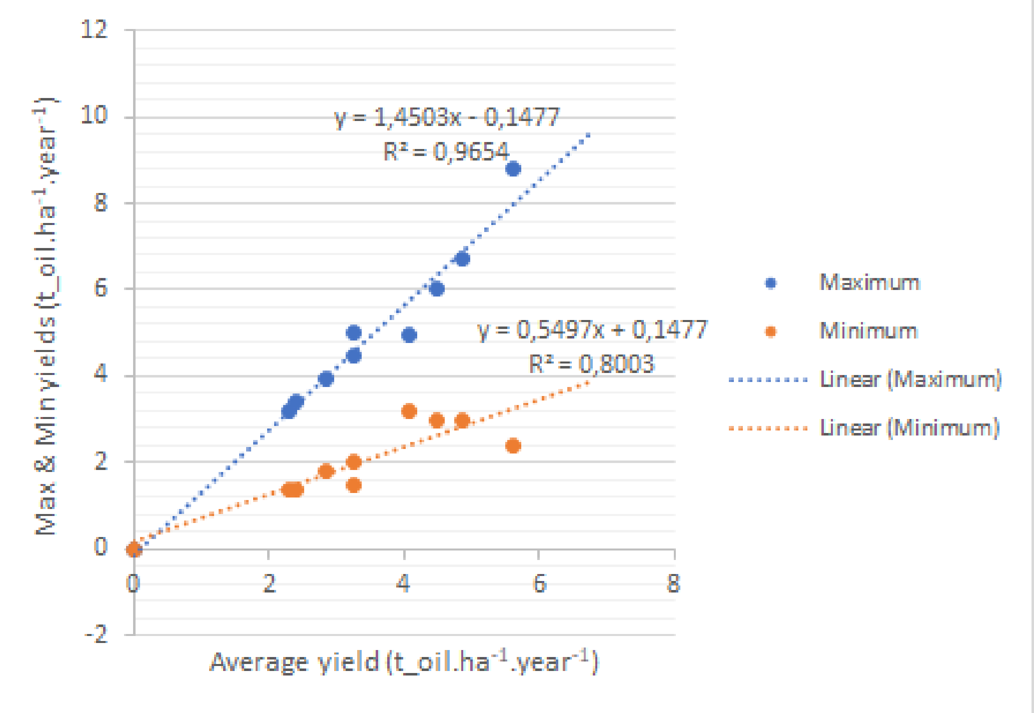
- Details are shown in the figures on the side. In some cases there are records of natural occurrence of macauba in areas that have been classified as of low suitability (red areas).
- In general, the exact locations of occurrence records are not presented in the literature, nor are estimates of productivity (for fruit and oil).
- And, as mentioned earlier, the soil map (soil suitability is an important parameter in the classification procedure) obviously has an imprecision associated with resolution.

Macauba oil yield (1)

- The state of the knowledge related to macauba does not allow the definition of a yield function. What has been done here is based on information available in the literature, and the literature mostly reports yields of non-commercial plantations. In this sense, the procedure used can lead to conservative results.
- The actual oil yield per unit area is a function of many factors, such as the age of the trees, the density of macauba trees per hectare, the weight of fresh fruits produced and the oil content in the pulp.
- IAC (2011) mentions that a typical total oil yield is about 6.2 $t.ha^{-1}.year^{-1}$ in the mature phase, being 80% oil from the pulp. In some texts, it is not clear whether the mentioned yield corresponds to the total production of oil (both from the pulp and the seeds) or only to the pulp oil.
- The macauba cultivation cycle has three stages: implantation (until the end of the fourth year after planting), the growth period (from year 5 to 9) and, finally, the mature phase, from year 10 to 30. There is no oil production in the first four years and oil yields grow during the fifth to ninth years, being almost stable since then.

Macauba oil yield (2)



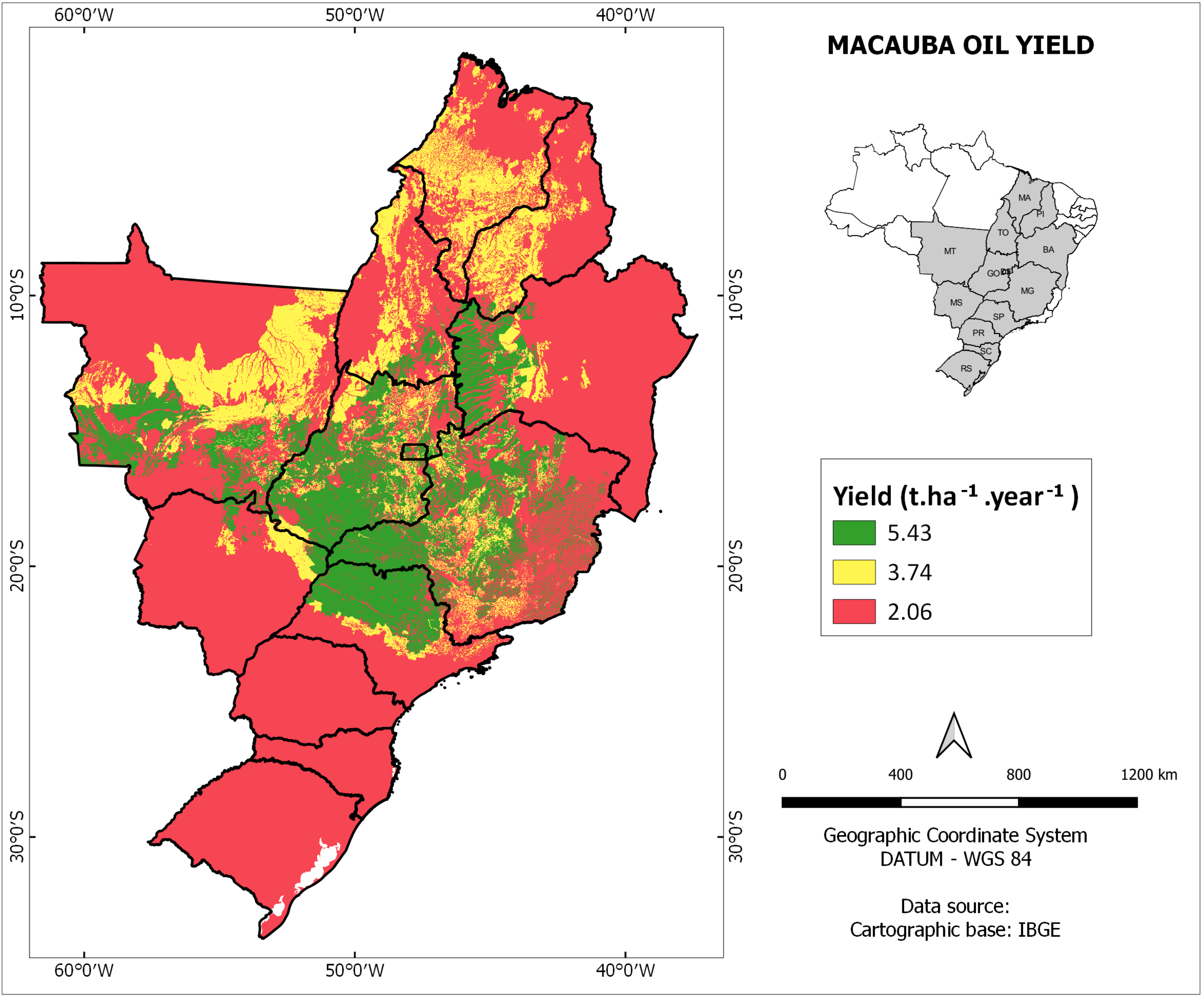


- Here, the estimate of the average yield of macaw palm oil (only oil from pulp) is based on 14 registers obtained from five sources; yields vary from 2.3 to 6.7 t of oil.ha^{-1}.year^{-1}, with an average of 4.08 t.ha^{-1}.year^{-1}. It was assumed that all these registers are for the mature phase.
- The figure below shows the correlation(s) obtained between maximum – and minimum yields – and average figures (based on nine registers, obtained from three sources).
- It was assumed that the oil yield during macauba's mature phase (year 10 to 30) in the regions with medium suitability would be 4.08 t of oil.ha^{-1}.year^{-1}. Based on the correlations, the yields for the regions with high and low suitability would be, respectively, 5.92 t.ha^{-1}.year^{-1} and 2.24 t.ha^{-1}.year^{-1}.
- Considering that the producing cycle is from year 5 to 30, and that yields are lower in the years 5 to 9, the assumed average yields in the whole producing cycle (26 years) are: for high suitability areas, 5.43 t.ha^{-1}.year^{-1}, 3.74 for the areas with medium suitability and 2.06 t.ha^{-1}.year^{-1} for the areas with low suitability.

Macauba oil yield (3)

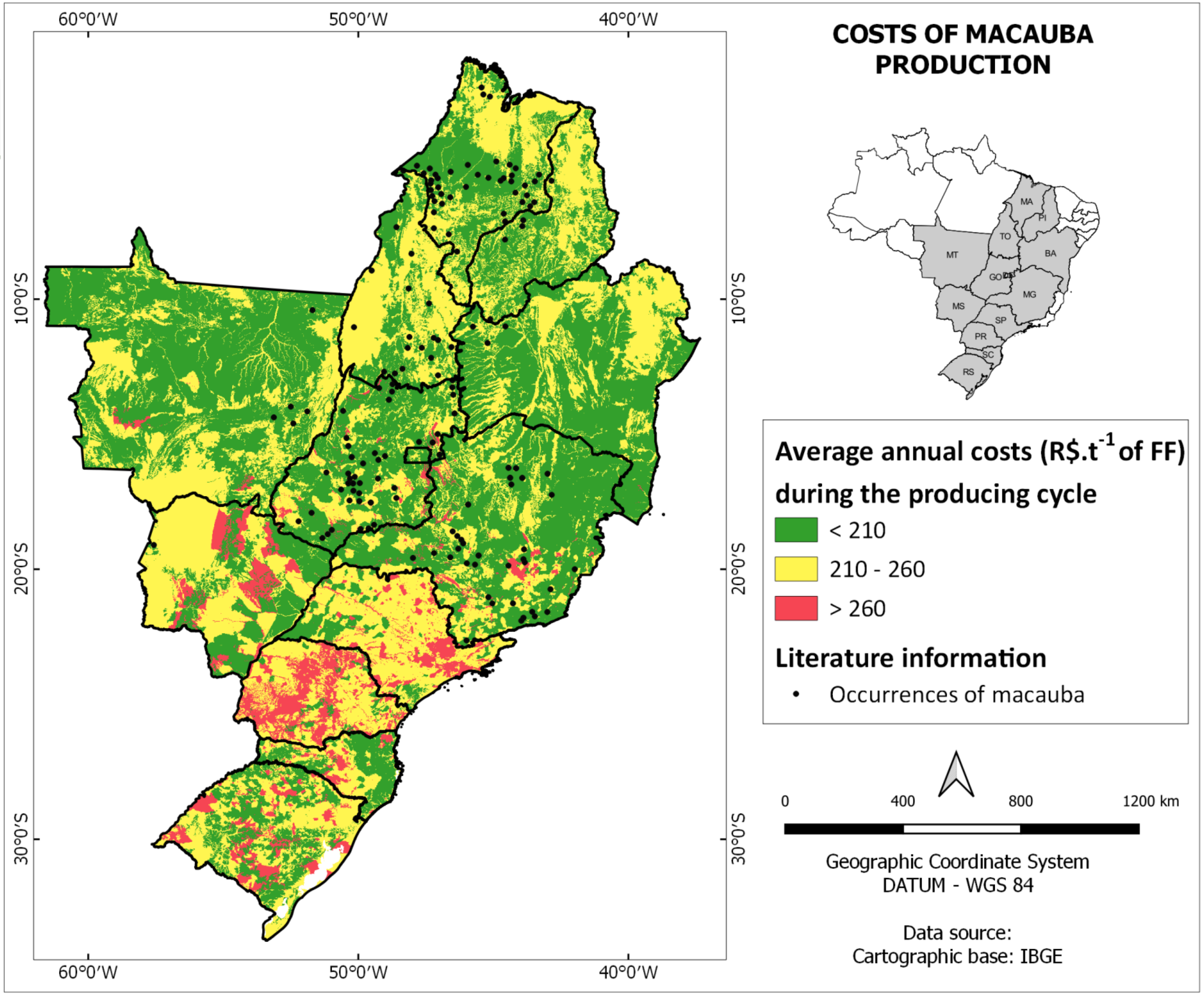
- Both for estimating yields and production costs, here it was assumed that the life cycle of the plantation is 30 years, with 26 years of fruit (and oil) production (20 year in the mature phase). It was assumed that plant density is from 350 to 400 plants per hectare.
- In the procedure it was first estimated the yield of fresh fruits (FF) that varies from 12.3 $t.ha^{-1}.year^{-1}$ in case of low productivity to 25.3 $t.ha^{-1}.year^{-1}$ in case of high productivity (19.4 $t.ha^{-1}.year^{-1}$ in the intermediate case). The oil content (ranging from 16.8% to 21.5%) was set in order to adjust the results to the values of oil yield previously mentioned.
- The oil yields defined here (ranging from 2.06 $t.ha^{-1}.year^{-1}$ to 5.43 $t.ha^{-1}.year^{-1}$; values for the whole cycle, and only for pulp oil) can be compared, for example, with the estimates presented by Colombo et al. (2018) that vary from 2.5 to 5.0 $t.ha^{-1}.year^{-1}$, and with the estimates done from data presented by Chagas (2018) (5.2 $t.ha^{-1}.year^{-1}$, for the whole sample of fruits, and 8.1 $t.ha^{-1}.year^{-1}$, for the best fruits).

Macauba oil yield (4)



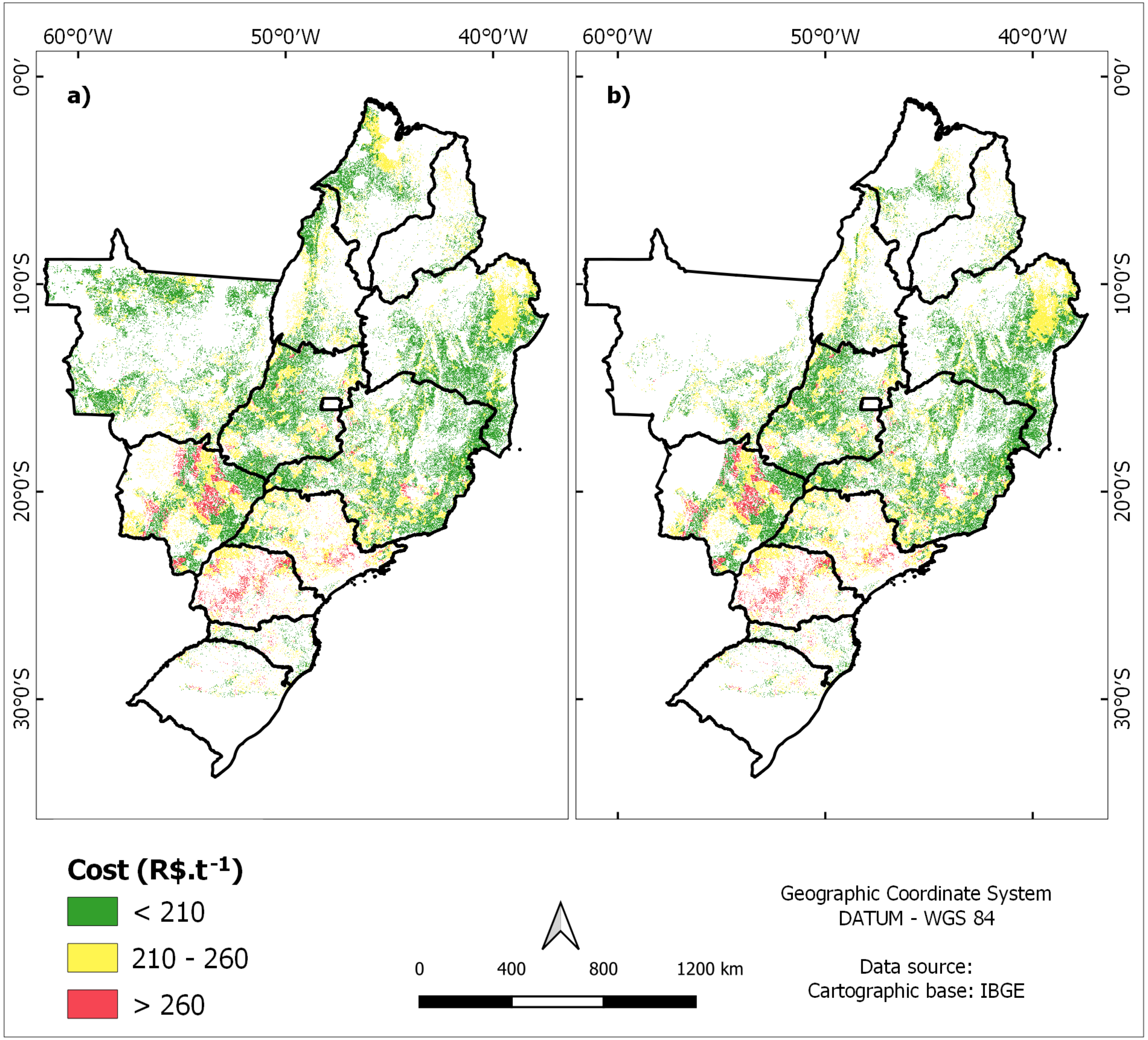
- While the oil yield was defined in association with suitability for macauba, its map is closely related to the suitability map, previously presented.
- The values are weighted averages for the entire cycle and only for pulp oil (mesocarp).

Costs of macaw production (1)



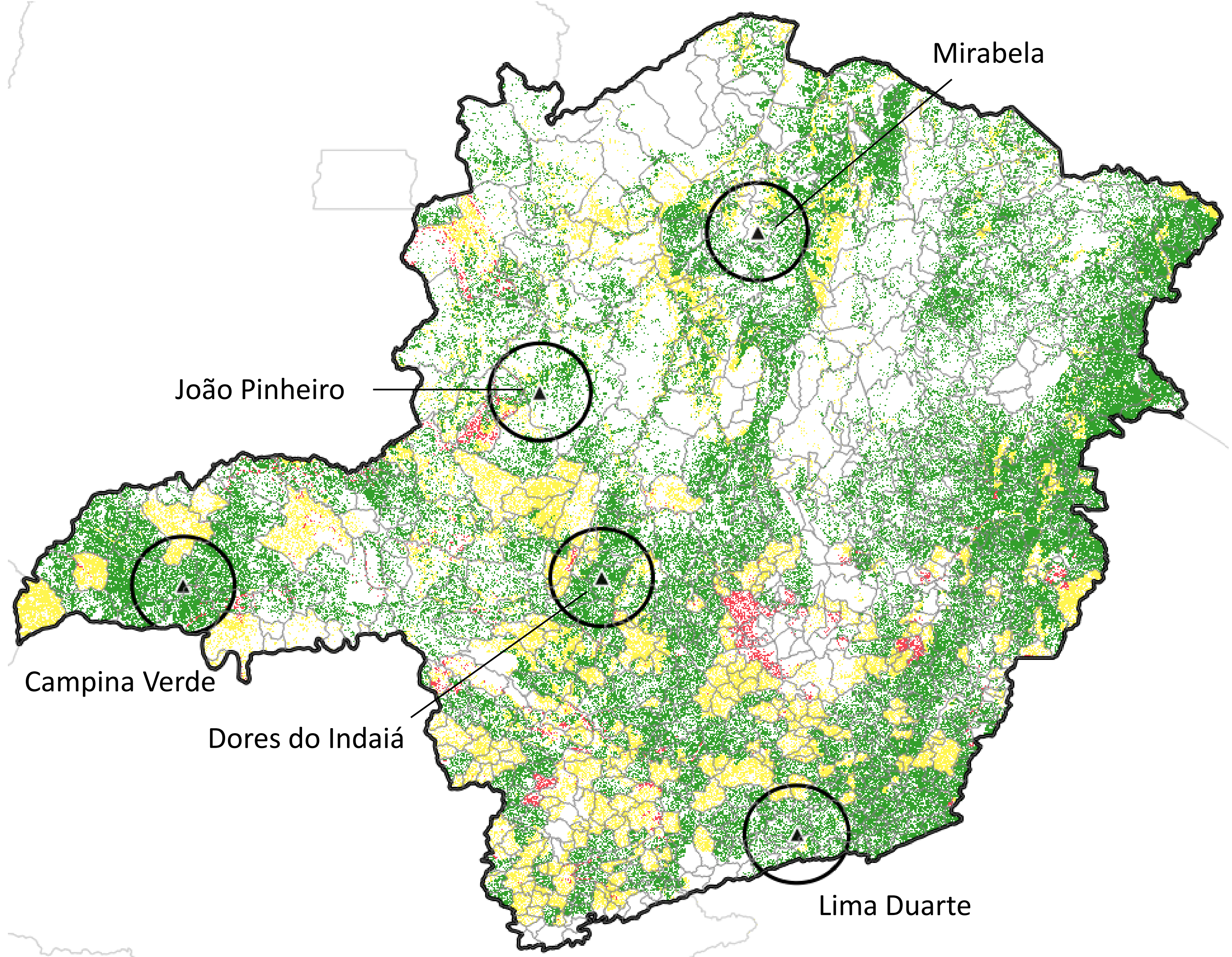
- The figure shows the distribution of estimated costs of macaw production in the twelve Brazilian states here considered. Costs are expressed in R$ (2018) per tonne of fresh fruits produced per year (on average, considering the producing cycle). In the figure, the dots indicate the sites of natural occurrence of macauba, according to the literature.
- Costs were estimated based on information presented by Chagas (2018) and the results were compared with estimates by Pimentel et al. (2017).
- The costs include the opportunity cost of land, all procedures before planting, manual and mechanized operations, necessary inputs, maintenance and harvesting.
- The costs are impacted by the estimated yields. They vary from 175 $R\$.t^{-1}$ of fresh fruits to 1,360 $R\$.t^{-1}$ per year (average 229 ± 52 $R\$.t^{-1}.year^{-1}$).

Costs of macaw production (2)

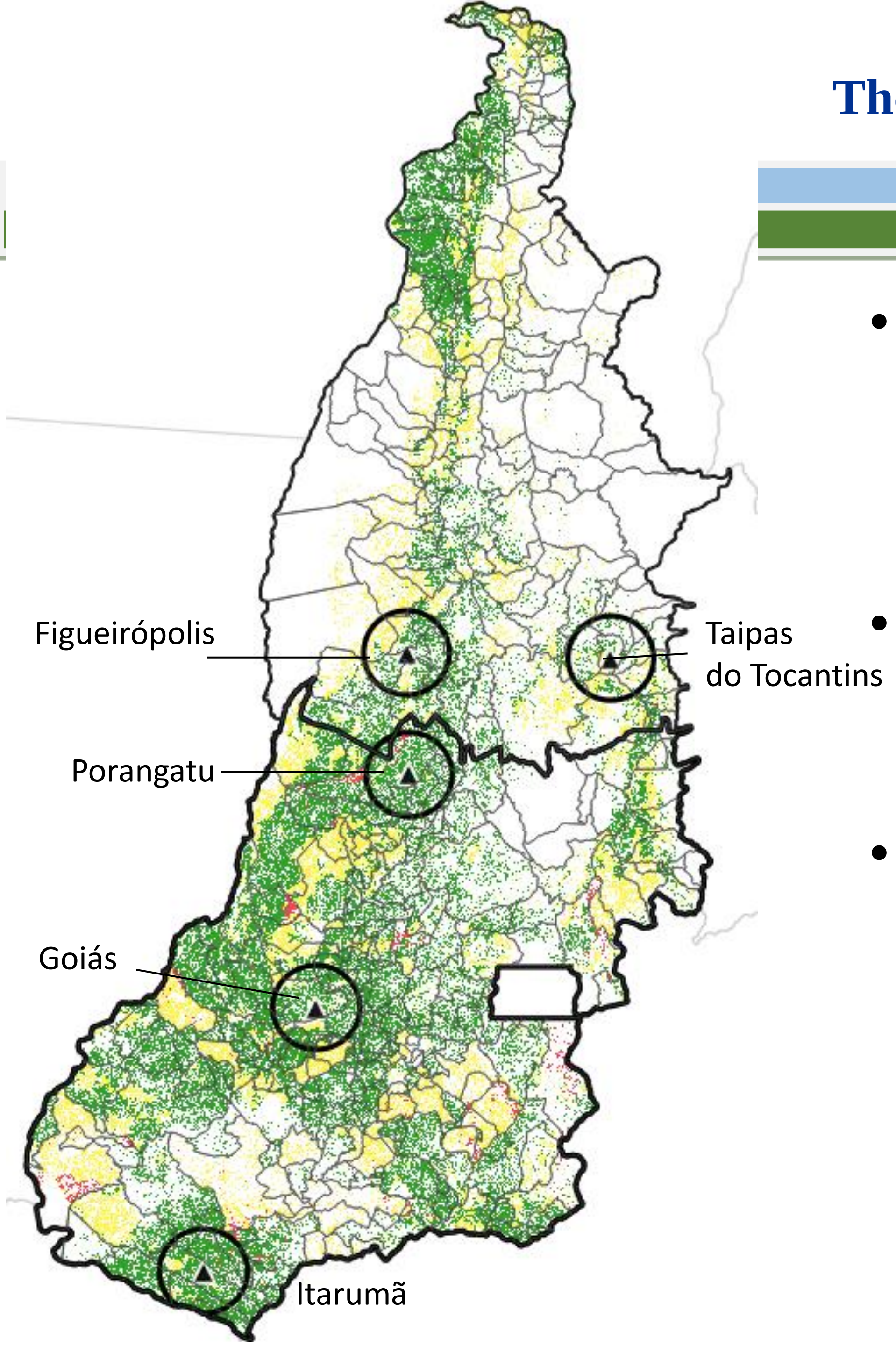


- Figures present the estimated annual costs of macauba production (R$.t^{-1} of fresh fruits), assuming displacement of pasturelands (in 2018) and excluding sensitive areas (see supplementary material).
- In the case of figure b) the Amazon and Pantanal biomes have been completely excluded, and this represents the most conservative solution. The results shown in this figure are those used in detailing the case study.

The choice of five municipalities in Minas Gerais



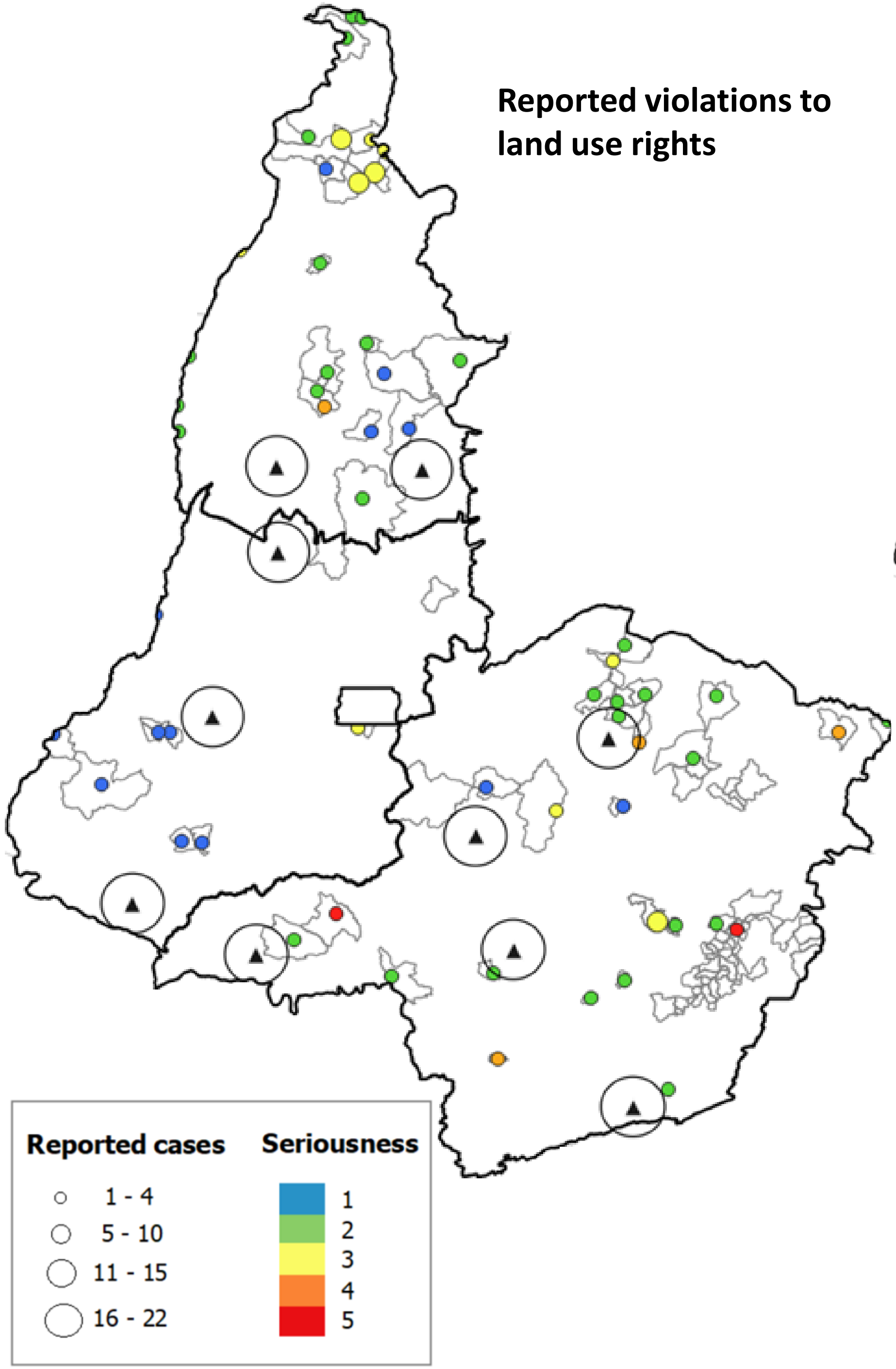
- The rationale is that extraction units would be located in selected municipalities and the area of influence was defined by a circle with 50 km radius, with center in the municipality.
- The municipalities chosen in Minas Gerais were: Lima Duarte, Dores do Indaiá, João Pinheiro, Mirabela e Campina Verde.
- In the first four there are initiatives for commercial production of macauba. Campina Verde was chosen because it is the center of an area with potentially low producing costs.

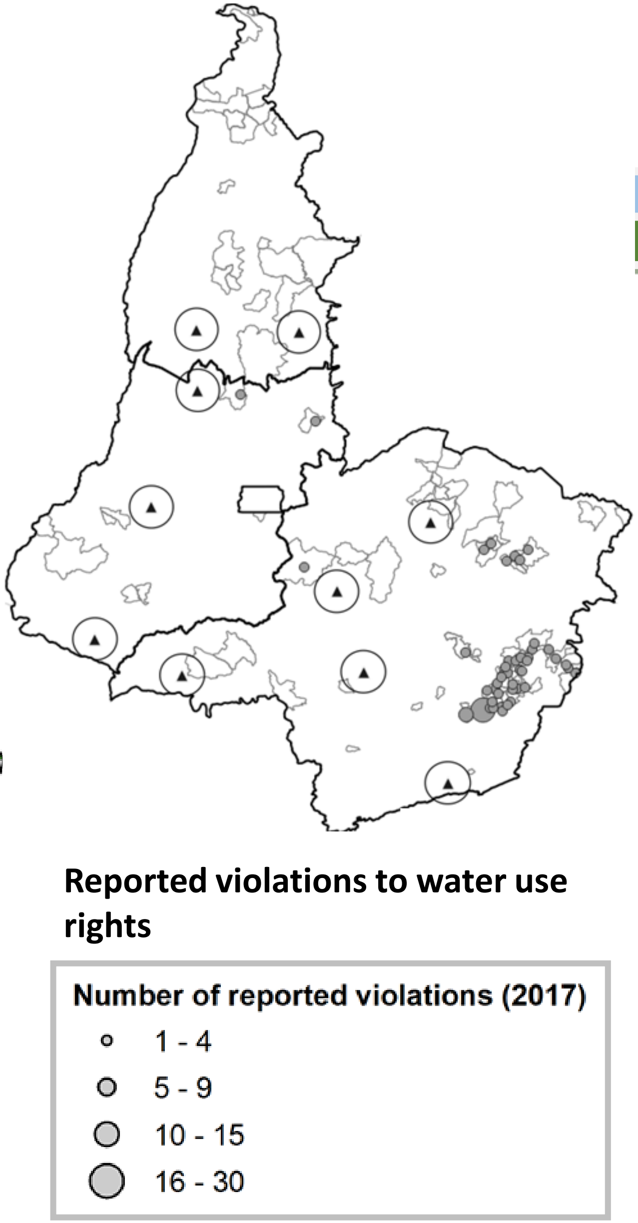


The choice of municipalities in Goiás and Tocantins

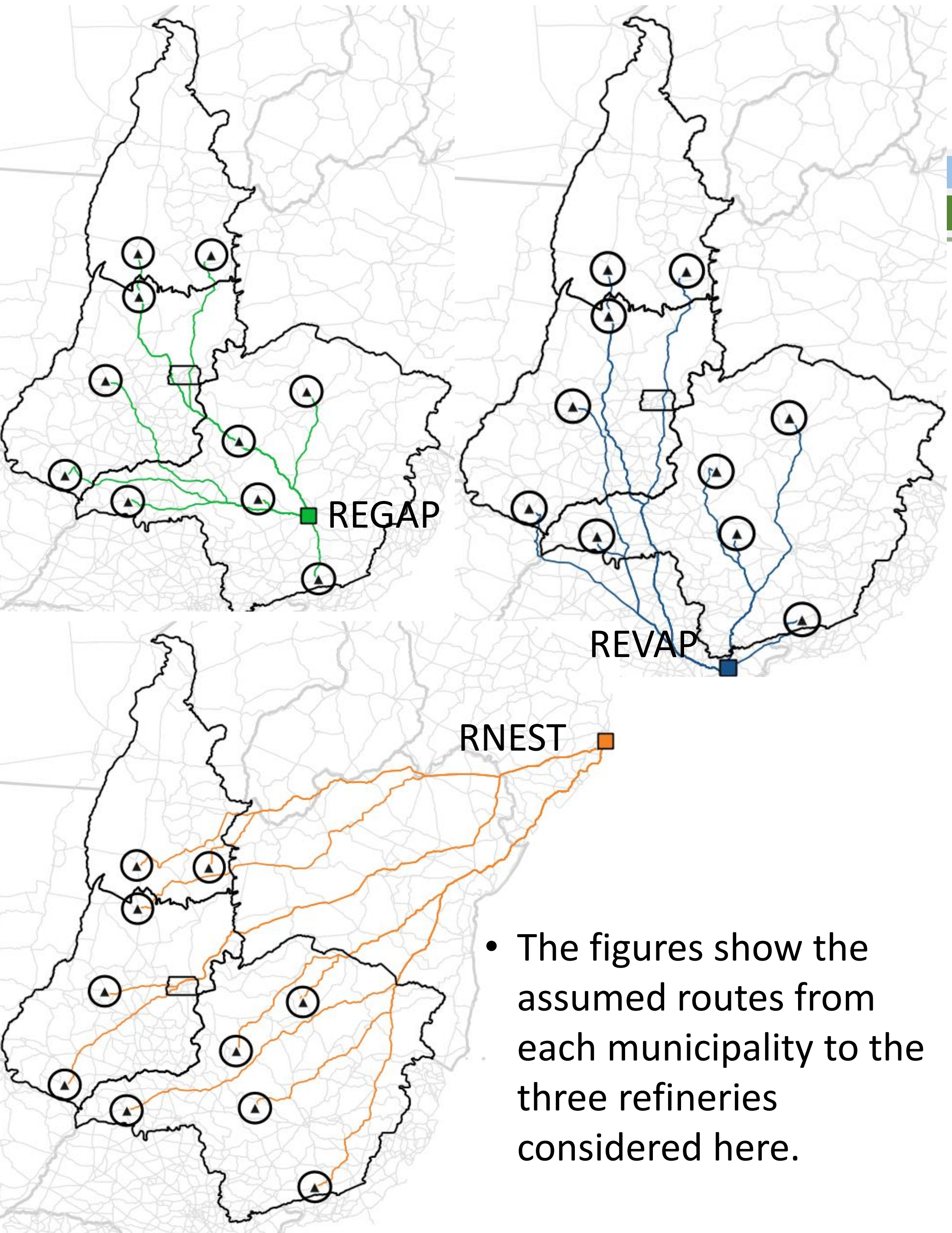
- The figure illustrates the exploratory procedure for the definition of the municipalities where there would be oil extractors and the areas of influence (the circles with a tringle in the center).
- The basic criterion was to search for areas with lower potential production costs, but areas where costs are intermediate were also defined.
- In Goiás state, the chosen municipalities were Itarumã (in the South), Goiás in the central part, and Porangatu (in the North). In Tocantis the municipalities chosen were Figueirópolis and Taipas do Tocantins (located in Southeast).

Checking the choices





- An additional procedure was the verification of recent reported violations to land use rights and water use rights. It was assumed that investors would take this information into account, aiming to reduce risks.
- The figures show the ten municipalities chosen, and their influence areas. The municipalities marked are those with registers of violation in recent years.
- In the procedure of assessing suitable production of macauba, the areas of municipalities with registers of violations were excluded.



- The figures show the assumed routes from each municipality to the three refineries considered here.

Locations and distances (in km)

Municipality	State	REGAP	REVAP	RNEST
Dores do Indaiá	MG	234	630	2,246
João Pinheiro	MG	443	937	2,064
Lima Duarte	MG	302	323	2,352
Mirabela	MG	577	1,012	1,765
Campina Verde	MG	709	700	2,641
Goiás	GO	1,005	1,143	2,426
Itarumã	GO	1,052	969	2,657
Porangatu	GO	1,195	1,401	2,201
Figueirópolis	TO	1,347	1,563	2,107
Taipas do Tocantins	TO	1,351	1,673	1,792

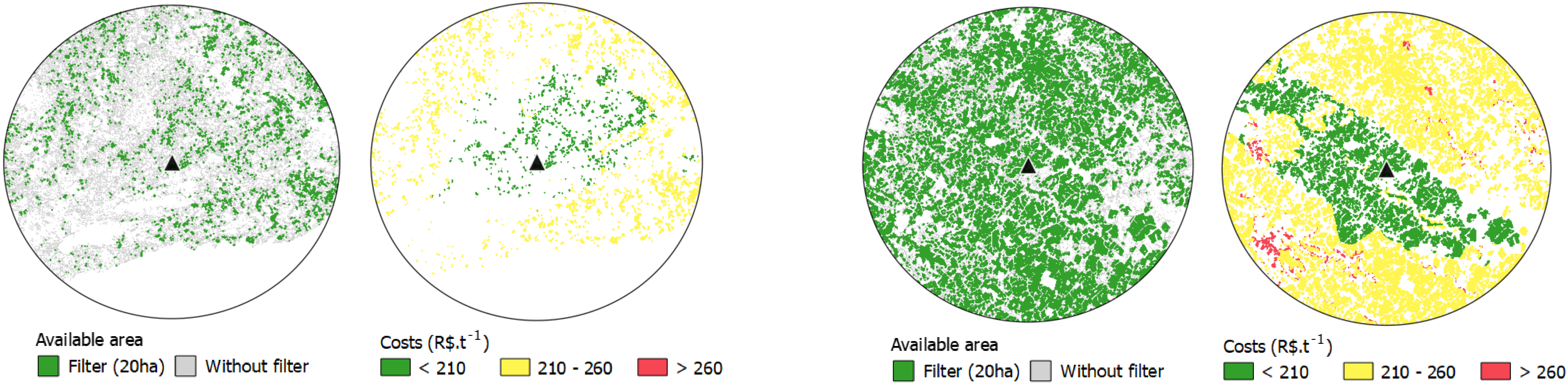
- The road distances could have an impact on the supply ranking. Only consider distances, sites around Mirabela are the best options for RNEST, while Lima Duarte is the best producer region for REGAP and REVAP. However, both are not priorities considering costs and the amount of oil to be produced.

Assessing potential macauba production / filtering the results (1)

Municipality	State	Area assessed (1,000 hectares)	Area adjusted (1,000 hectares)	Reduction (%)
Dores do Indaiá	MG	469.68	213.28	55
João Pinheiro	MG	240.58	76.38	68
Lima Duarte	MG	340.13	88.82	74
Mirabela	MG	241.20	73.76	69
Campina Verde	MG	411.00	266.06	35
Goiás	GO	466.84	200.98	57
Itarumã	GO	541.57	419.67	23
Porangatu	GO	424.90	179.98	58
Figueirópolis	TO	345.32	163.71	53
Taipas do Tocantins	TO	234.98	71.44	70

- In assessing the area available for the production of macauba within the circles, the results (after exclusion of sensitive areas) were filtered to explore the fact that commercial production would require a minimum contiguous cultivation area. Here, 20 hectares was the minimum area considered.
- The impacts on results are shown in the table. In some cases, the estimated area is reduced by 70%, or even more.

Assessing potential macauba production / filtering the results (2)



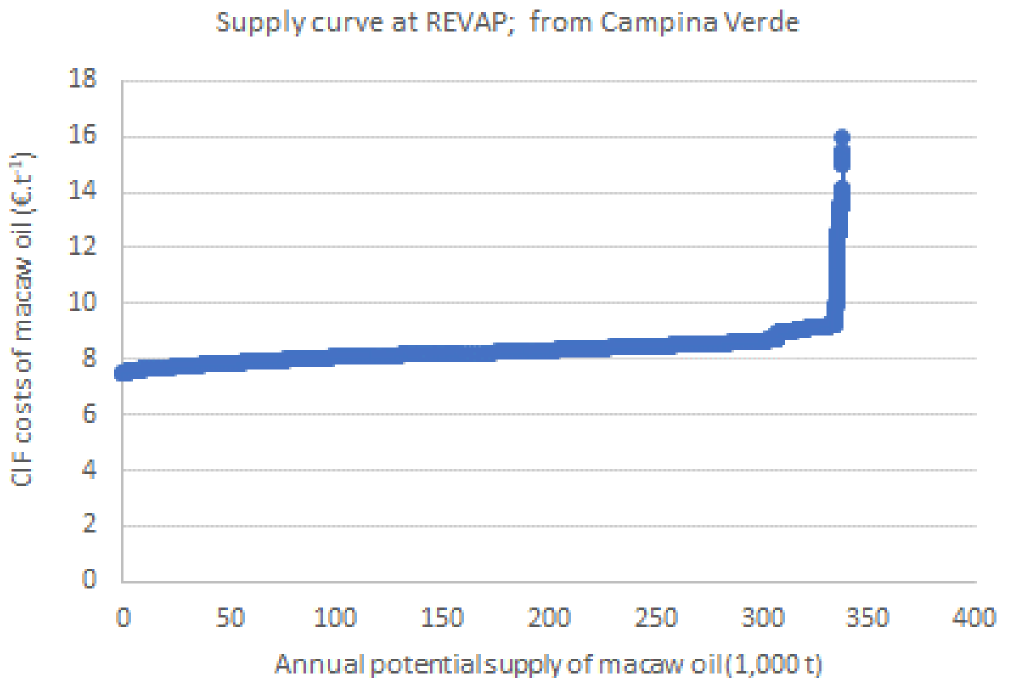
- The figures in the left side are related to Lima Duarte (MG), while those in the right side are for the Itarumã case (GO). Among the ten cases reported here, these figures illustrate, respectively, the largest and the smallest impact due to the filtering procedure.
- In the Lima Duarte case, the remaining area with the lowest production cost is only about 20% of the total quantified area, while in case of Itarumã this share is about 60%.

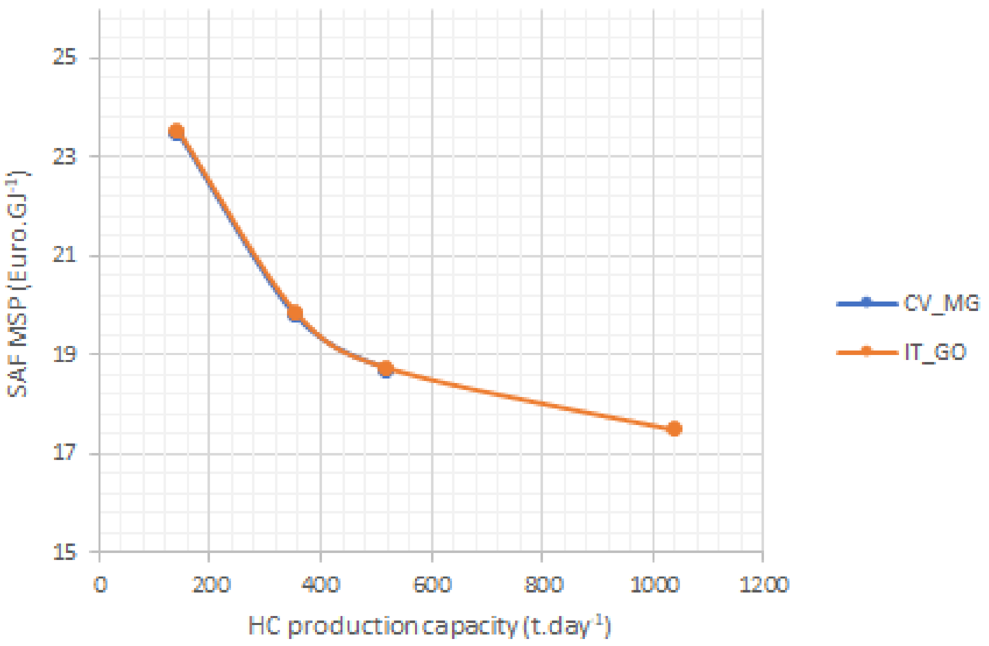
First set of results

Municipality	State	Estimated production		CIF costs at (€.GJ^{-1})		
		Fresh fruits (kt.$year^{-1}$)	Oil (kt.$year^{-1}$)	REGAP	REVAP	RNEST
Dores do Indaiá	MG	1,028.47	210.82	9.58	9.95	10.99
João Pinheiro	MG	407.11	85.34	9.53	9.92	10.62
Lima Duarte	MG	286.23	53.39	9.17	9.20	10.56
Mirabela	MG	385.49	81.07	9.69	10.02	10.50
Campina Verde	MG	1,576.01	338.06	10.26	10.25	11.44
Goiás	GO	1,091.43	230.50	10.19	10.29	11.05
Itarumã	GO	2,411.78	514.12	10.46	10.40	11.40
Porangatu	GO	1,000.16	212.63	9.97	10.11	10.58
Figueirópolis	TO	587.09	113.24	10.49	10.63	10.94
Taipas do Tocantins	TO	292.19	58.92	9.86	10.06	10.13

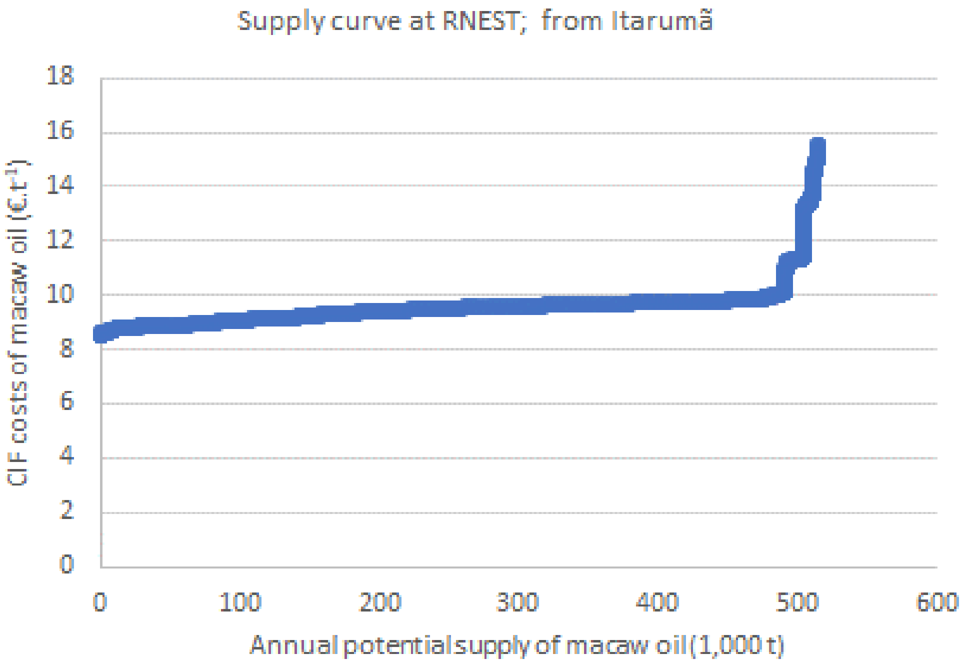
- For the ten areas studied the results of the assessment are presented in the table: the annual estimated production of fresh fruits (average for the whole cycle) and oil (from pulp), besides CIF costs of oil at the three refineries considered.
- Based on these results, and knowing the required macaw oil demand for each industrial capacity, two cases were evaluated: feedstock production exclusively in Campina Verde (MG) and Itarumã (GO).
- For both municipalities there is a small advantage for the production at REVAP, comparing with the production at REGAP.

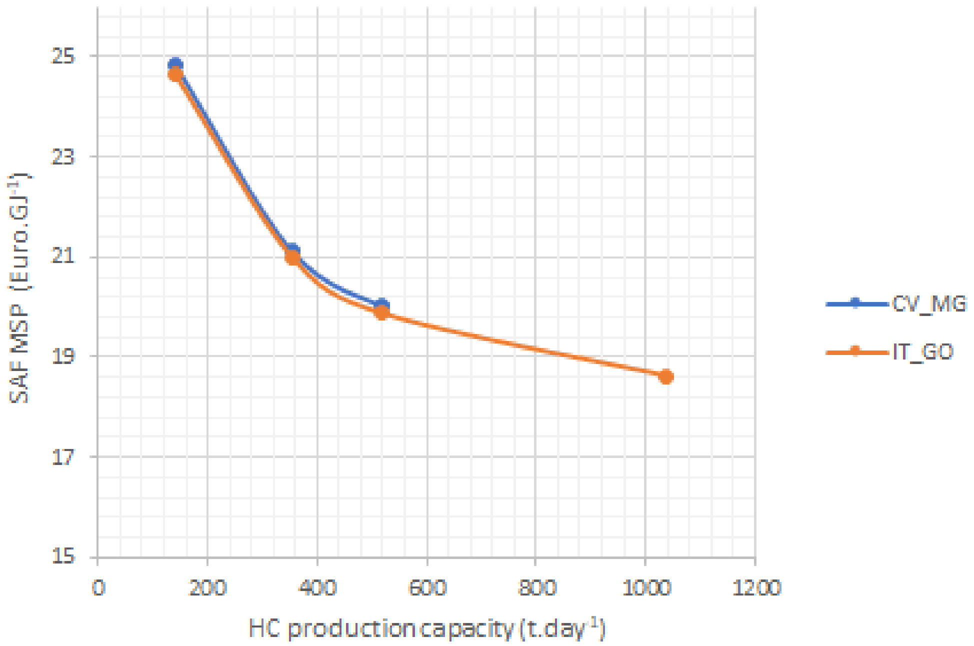
SAF production at REVAP





- As an illustration, upper figure shows the macaw oil supply curve from Campina Verde, at REVAP.
- Lower figure shows the estimated SAF MSP (minimum selling prices) as function of the daily capacity of hydrocarbons production. The economic results are based on the estimated MSP of SAF produced at REVAP, exclusively using the feedstock supplied from Campina Verde (CV) or Itarumã (IT).
- Five capacities were considered, but there is not enough oil for the largest capacity (2,075 t.day^{-1}). In fact, only based on the oil supply from Campina Verde, it is not possible the production of 1,038 t.day^{-1} either.
- For the smallest industrial capacities, the difference in MSP is absolutely irrelevant (0.5%, or even less).
- The MSP would be 18.7 €.GJ^{-1} for the production of 519 t of hydrocarbons per day (75 t.day^{-1} of SAF), and this could be reduced to 17.5 €.GJ^{-1} in case of the largest possible industrial capacity (1,038 t.day^{-1} of hydrocarbons, or 150 t.day^{-1} of SAF).





SAF production at RNEST

- Upper figure shows the macaw oil supply curve from Itarumã, at RNEST.
- Lower figure shows the estimated MSP as function of the daily capacity of hydrocarbons production. The economic results are based on the estimated MSP of SAF produced at RNEST, exclusively using the feedstock supplied from the two municipalities considered (Campina Verde and Itarumã).
- As mentioned in the previous case, there is not enough macaw oil for the largest industrial capacity (2,075 $t.day^{-1}$). Based only on the supply from Campina Verde, it is not possible the production of 1,038 $t.day^{-1}$ either.
- There is a tiny advantage of producing with macaw oil from Itarumã, but the difference is less than 1% in the cases in which the comparison is possible.
- The MSP would be about 20 $€.GJ^{-1}$ for the production of 519 t of hydrocarbons per day (75 $t.day^{-1}$ of SAF), and this could be reduced to 18.6 $€.GJ^{-1}$ in case of the largest possible industrial capacity (1,038 $t.day^{-1}$, or 150 $t.day^{-1}$ of SAF).

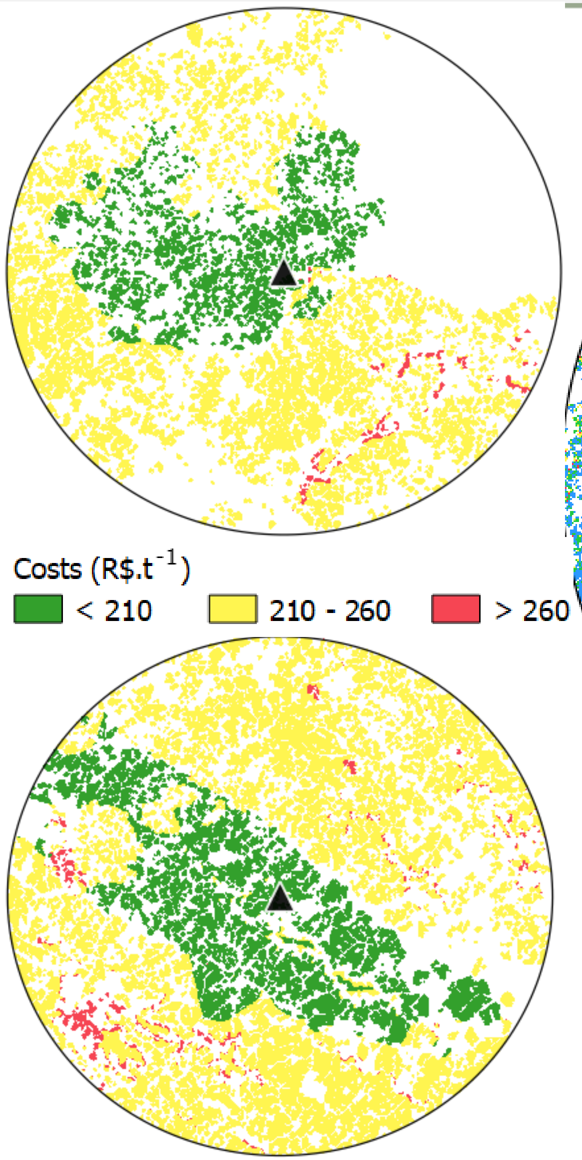
Considering the level of soil degradation in pasturelands

Table below shows the estimated shares of pasturelands (%) according to the four groups considered. The classification of pasturelands according to degradation levels is based on the normalized vegetative vigor index (NDVI) (e.g. no degradation > 0.6; severe degradation < 0.4) (LAPIG, 2018).

Municipality	State	No degradation	Slight	Moderate	Severe
Dores do Indaiá	MG	40.4	22.0	17.0	20.6
João Pinheiro	MG	6.0	9.9	18.4	65.7
Lima Duarte	MG	62.4	20.4	10.5	6.7
Mirabela	MG	26.9	18.5	19.6	35.0
Campina Verde	MG	38.0	29.6	21.1	11.3
Goiás	GO	46.6	25.3	17.1	11.0
Itarumã	GO	33.3	26.7	22.5	17.6
Porangatu	GO	18.5	18.3	22.1	41.0
Figueirópolis	TO	6.8	10.9	22.0	60.3
Taipas do Tocantins	TO	12.6	20.4	29.9	37.1

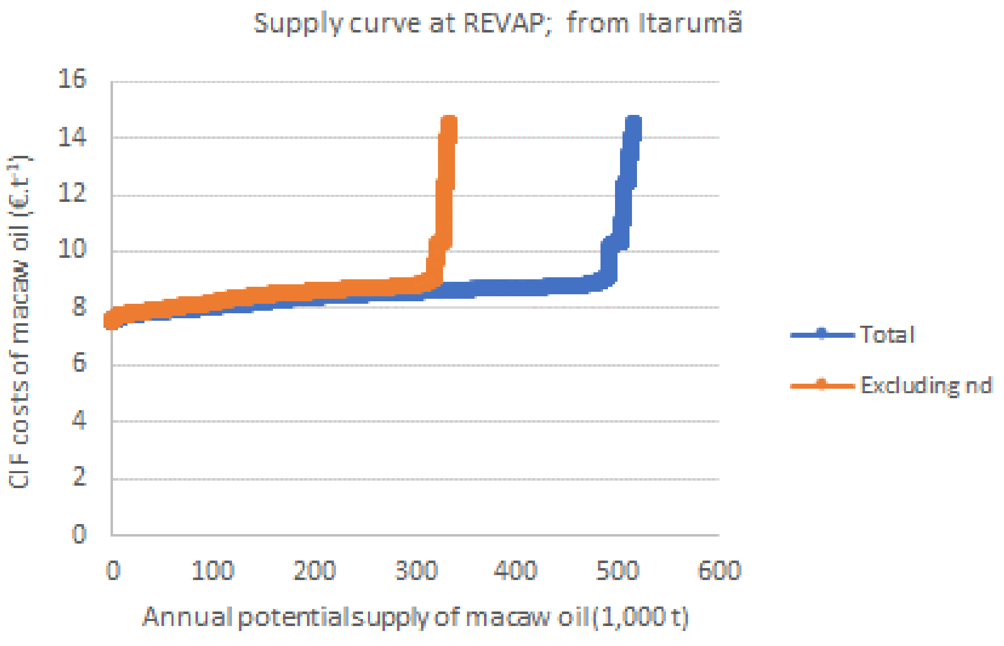
- An option to reduce iLUC (induced Land Use Change) risks is the priority production on degraded lands. The impact of such alternative was assessed considering the production of macauba only on degraded pasturelands, both in Campina Verde and Itarumã.
- Assumptions on defining degraded pasturelands is presented in the Supplementary Material.
- More information and the assessment of impacts on the MSP of SAF production (at REVAP and RNEST) is presented in the following slides.

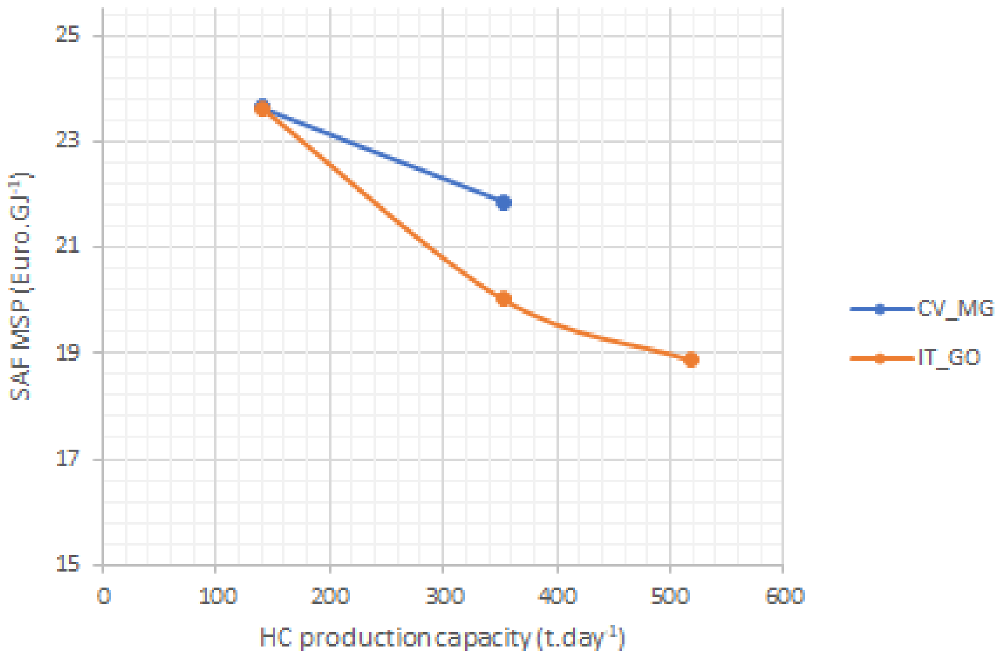
Soil degradation in pasturelands: Campina Verde & Itarumã



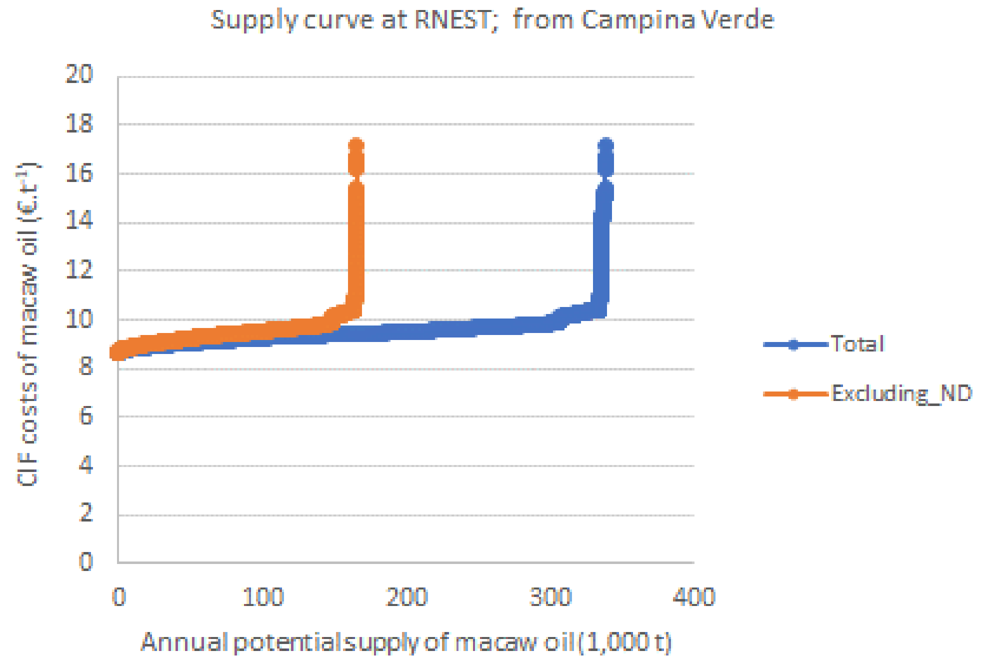
- Left side, on the top, figure for the estimated production costs of fresh fruits around Campina Verde (MG); on the bottom, the estimated costs around Itarumã (GO).
- Top figures: left side, distribution of no-degraded and degraded (at some level) pasturelands around Campina Verde; right side, the same for Itarumã.

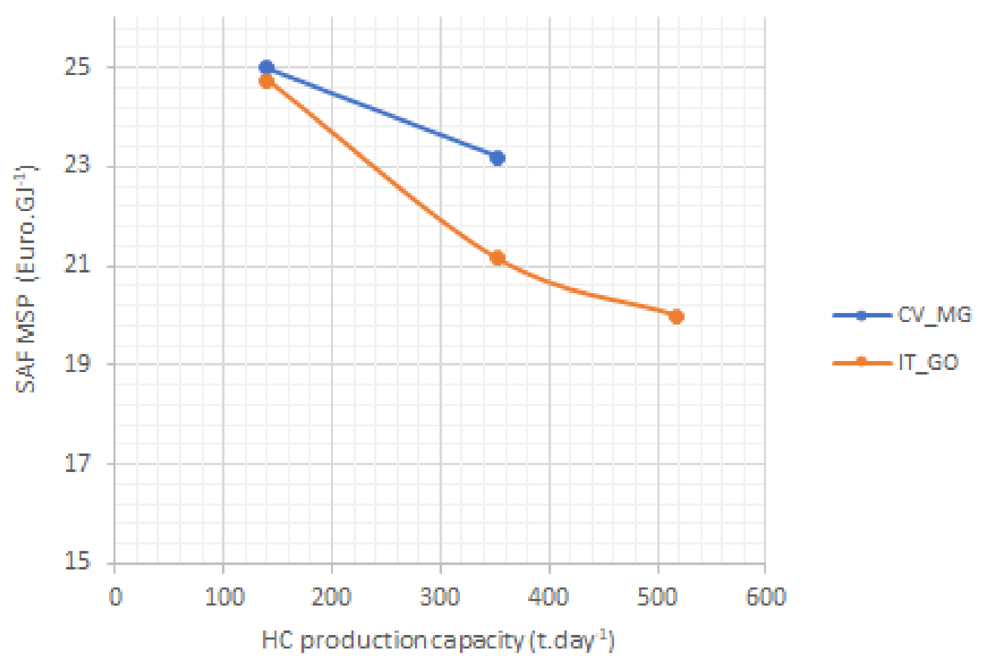
SAF production at REVAP – excluding non-degraded pasturelands





- As an illustration, the upper figure shows the macaw oil supply curves at REVAP (supply only from Itarumã), comparing the potential total supply and when production in non-degraded pastures is excluded.
- Lower figure shows the estimated MSP of SAF as function of the daily capacity of hydrocarbons production, only for the restricted case (excluding non-degraded pasturelands) and supply exclusively from Itarumã (IT) and Campina Verde (CV).
- The hypothesis assumed is that the soil would be recovered before the beginning of the macauba cycle. The costs would be paid for what would be cropped in the recovery procedure. Thus, there would be no impact on productivity or production costs of macauba oil but, on the other hand, the start of its cycle would be delayed.
- Not using non-degraded lands, the potential oil supply at REVAP, from Itarumã (upper figure), would be reduced by more than 35%.
- The impact on the economic results (based on the MSP) would be small for the smallest industrial capacities, but the reduction in supply would impact the results of the higher capacity units. Clearly the exclusive supply from Itarumã is better option than from Campina Verde.
- The MSP would be 18.9 €.GJ^{-1} for the production of 519 t of hydrocarbons per day (75 t.day^{-1} of SAF).

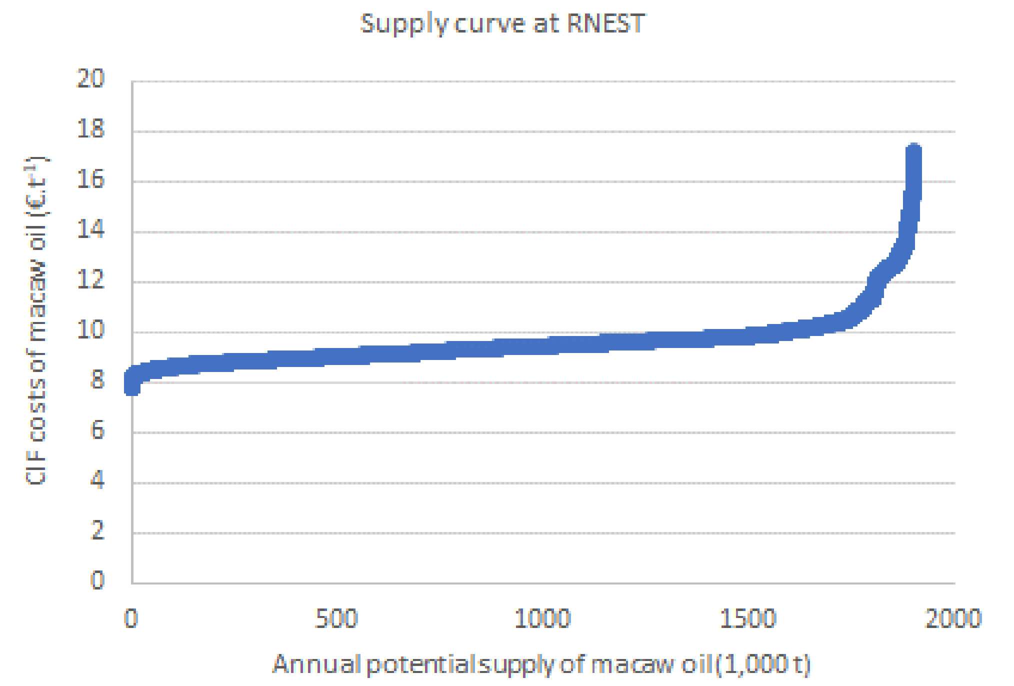


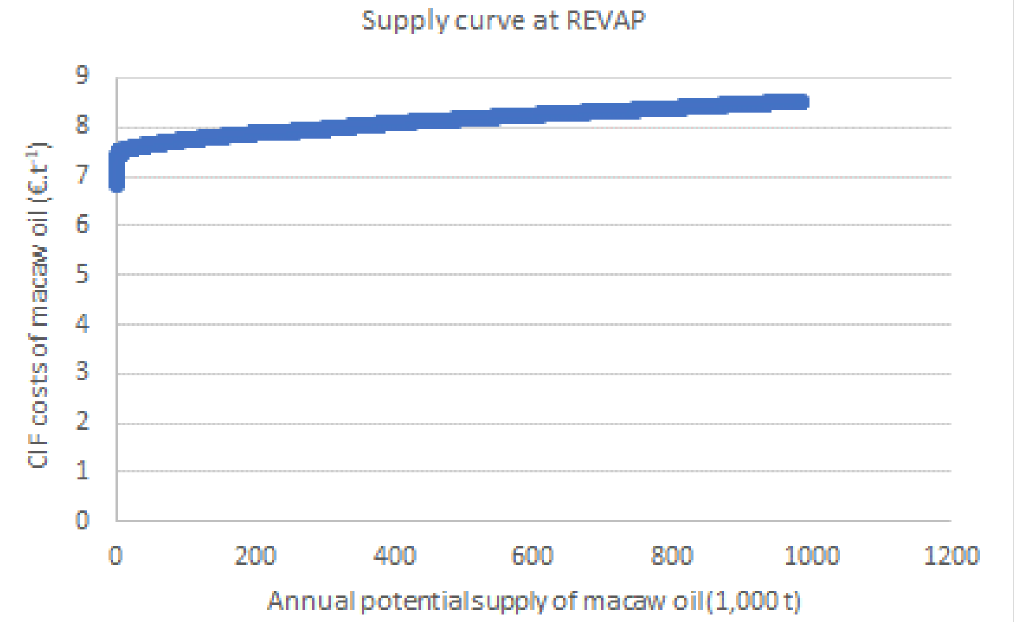


SAF production at RNEST – excluding non-degraded pasturelands

- Upper figure shows the macaw oil supply curves at RNEST (only from Campina Verde), comparing total supply and the results when only degraded pasturelands (at some level) are considered.
- Lower figure shows the estimated MSP of SAF as function of the daily capacity of hydrocarbons production, only for the restricted case (i.e. no production in non-degraded pasturelands).
- In the restricted case the potential oil supply from Campina Verde would be reduced by about 50%, with a significant impact on industrial capacities.
- Here, once more, it is clear the advantage of the exclusive supply from Itarumã, compared with Campina Verde.
- The MSP of SAF would be 21.1 €.GJ^{-1} for the production of 353 t of hydrocarbons per day (51 t.day^{-1} of SAF) assuming all supply from Itarumã, and 23.2 €.GJ^{-1} if all macaw oil would come from Campina Verde.

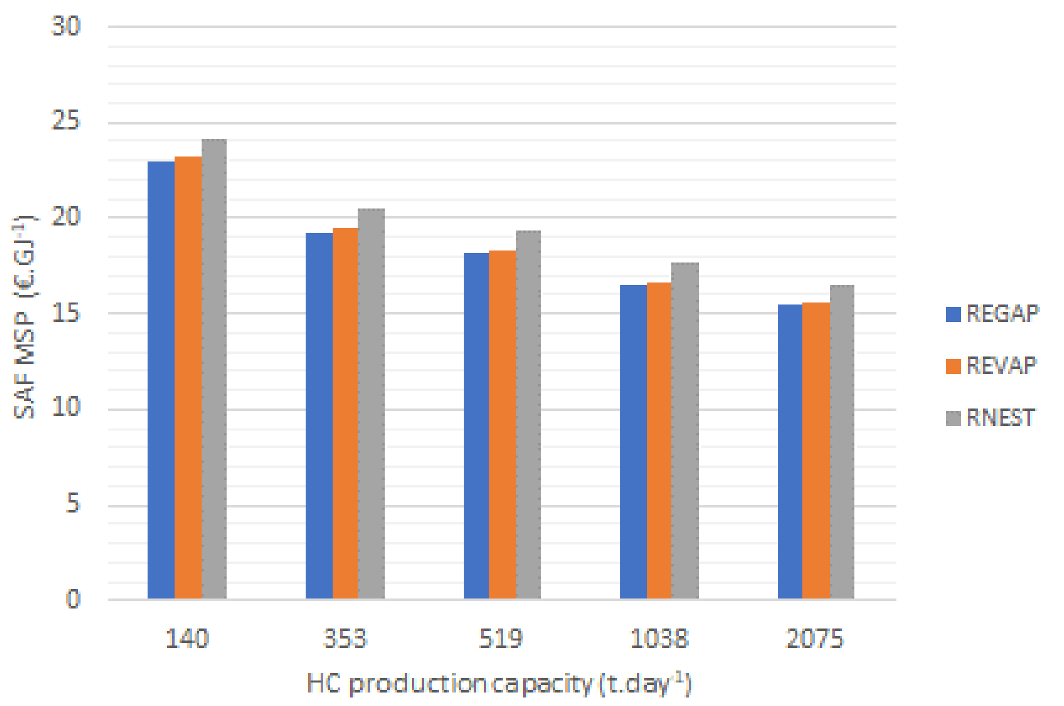
Combined supply of macaw oil





- The two figures show the macaw oil supply curve, combining all ten potential supply sites here considered.
- The upper figure is for the total potential supply at RNEST, summing-up 1,9 million tonnes.year^{-1}. In this case, the CIF costs vary from 7.8 to 17.2 €.GJ^{-1}.
- The second curve, for oil supply at REVAP, is the segment up to 986 kt.year^{-1}, which is the amount required by the largest industrial capacity considered (2,075 t.day^{-1} of hydrocarbons, or 300 t.day^{-1} of SAF). It is assumed a 20% margin, since the production cycle has some years of non-production (four years out of 30).
- The supply curve at REGAP is quite similar to the curve at REVAP, with costs that are about 1.4-3.4% lower. The oil costs at RNEST are at least 10% higher than at REVAP.

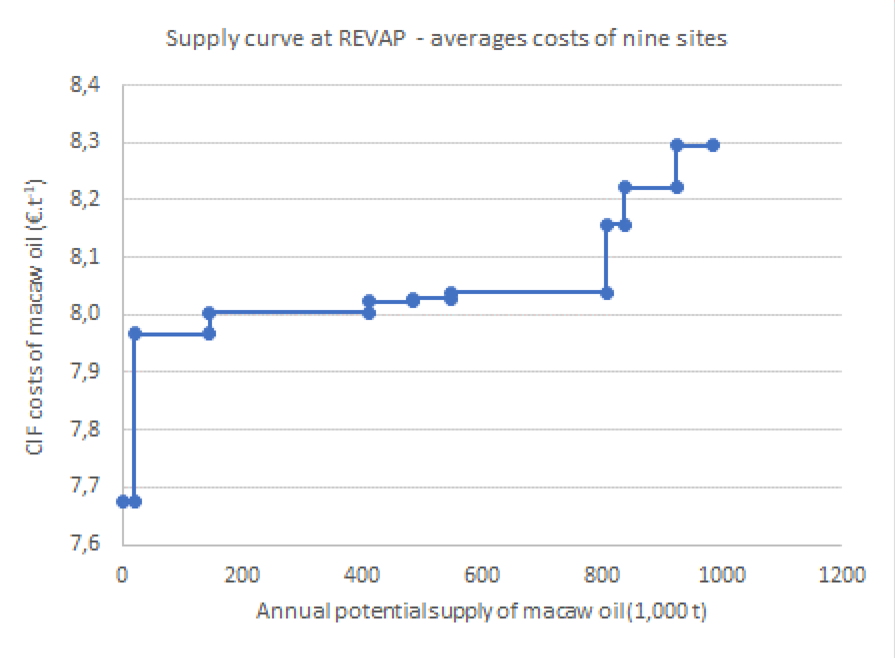
Results of SAF production, considering combined supply



- Another figure of comparison is the market jet fuel price. An estimate based on Platts Global Index was 622 €.t^{-1} in May 2018.

- The figure shows the estimated MSP of SAF production from macaw oil in three refineries. Due to the supply sites here considered, MSP is higher in case of RNEST (5-7% compared to the lower values) and is almost similar in case of REVAP and REGAP (the difference is no higher than 1.2%).
- The highest MSP are about to 23-24 €.GJ^{-1} (982-1034 €.t^{-1}) in case of the smallest industrial capacity and in the 15.4 to 16.5 €.GJ^{-1} (661-707 €.t^{-1}) range for the highest industrial capacity.
- MSP results should be compared to 29 €.GJ^{-1} (1,241 €.t^{-1}), which is the figure presented by de Jong et al. (2015) considering the production based on HEFA pathway, from UCO (used cooking oil), in Europe.

Excluding small contributions – production at REVAP

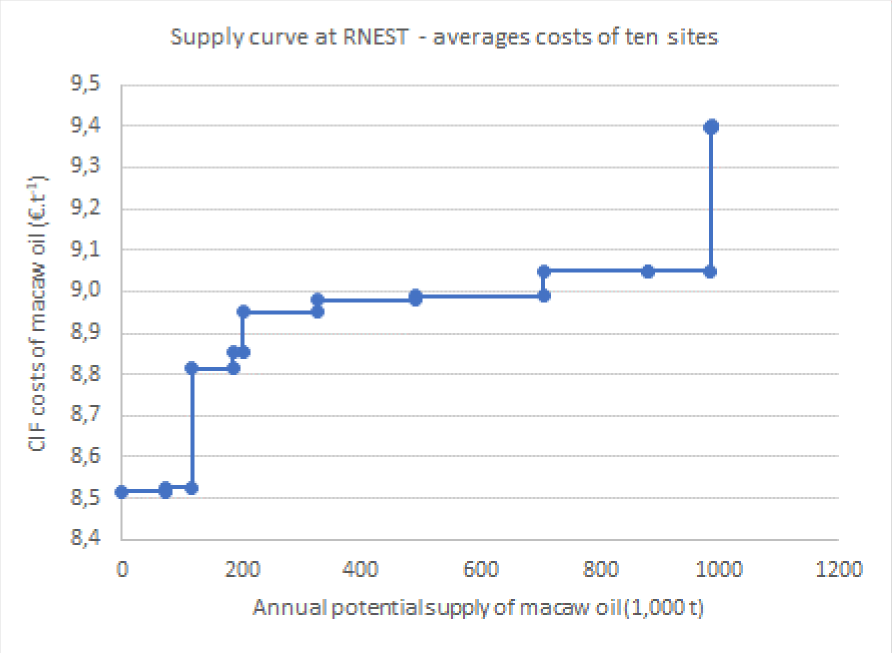


- Figure shows the combined supply curve at REVAP, based on the average CIF costs of oil. Costs vary from 7.67 to 8.29 $€.GJ^{-1}$ (8.0 $€.GJ^{-1}$, on average, for the total supply of 986 $kt.year^{-1}$).

Supply site	Oil supply ($kt.year^{-1}$)	Supply share (%)	Average CIF cost ($€.GJ^{-1}$)
Lima Duarte (MG)	18.9	**1.9**	7.67
Dores do Indaiá (MG)	128.0	13.0	7.97
Campina Verde (MG)	267.0	27.0	8.00
Mirabela (MG)	71.8	7.3	8.02
João Pinheiro (MG)	64.6	6.5	8.03
Itarumã (GO)	259.5	26.3	8.04
Taipas do Tocantins (TO)	29.2	**3.0**	8.16
Goiás (GO)	86.5	8.8	8.22
Porangatu (GO)	62.0	6.3	8.29

- The contribution from Lima Duarte and Taipas do Tocantins are less relevant, and were not considered in detailing this exercise.
- It is concluded that even excluding these two sites the impacts are negligible, as the average CIF cost only rise slightly (to 8.07 $€.GJ^{-1}$)

Excluding small contributions – production at RNEST



Supply site	Oil supply (kt.year^{-1})	Supply share (%)	Average CIF cost (€.GJ^{-1})
Mirabela (MG)	71.8	7.3	8.52
Taipas do Tocantins (TO)	44.7	4.5	8.53
João Pinheiro (MG)	69.2	7.0	8.81
Lima Duarte (MG)	16.3	**1.6**	8.85
Dores do Indaiá (MG)	127.5	12.9	8.95
Porangatu (GO)	163.7	16.6	8.98
Itarumã (GO)	212.9	21.6	8.99
Campina Verde (MG)	175.1	17.7	9.05
Goiás (GO)	105.5	10.7	9.05
Figueirópolis (TO)	0.7	**0.1**	9.40

- Figure shows the combined supply curve at RNEST, based on the average CIF costs of oil. Costs vary from 8.52 to 9.40 €.GJ^{-1} (8.85 €.GJ^{-1}, on average, for the total supply of 986 kt.year^{-1}).

- For the production at RNEST, similar analysis was done, with the exclusion of Lima Duarte and Figueirópolis. Again, it is concluded that the impacts on the MSP of SAF are negligible, as the oil's average CIF cost is kept almost constant.

Analysis of the set of results (1)

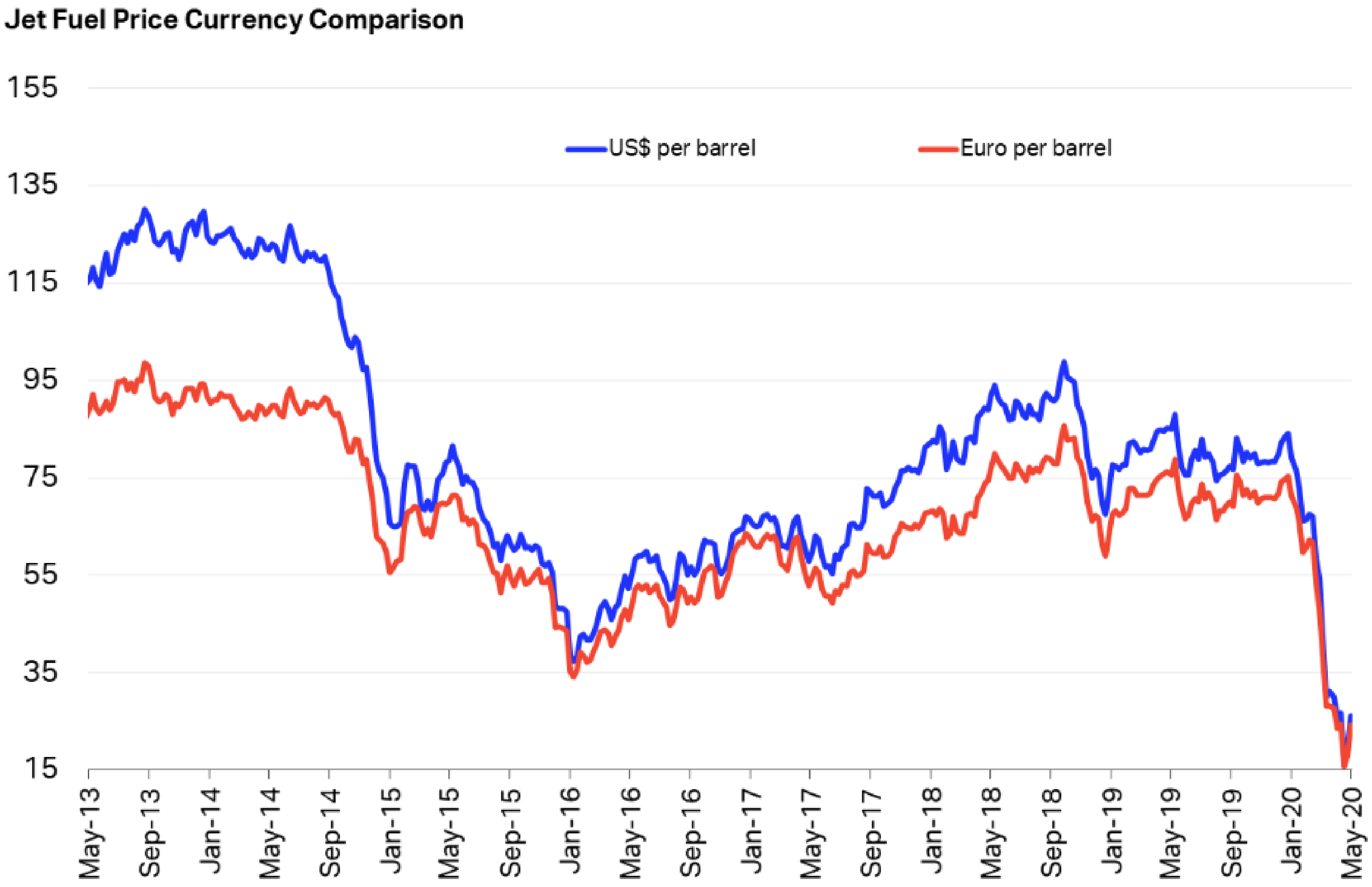
- Table summarizes the economic results of the studied cases.
- The results correspond to the lower MSP in the production range.
- The production in the largest industrial plant considered (300 t.day^{-1}, or 122.6 million litres of SAF per year) corresponds to 3% of the national consumption of jet fuel in 2018.

Production at	MSP (€.t^{-1})	MSP (€.GJ^{-1})	Case	Production size[4]
REVAP	748.8	17.5	Itarumã/no restriction[1]	150.1 t.day^{-1}
REVAP	807.6	18.9	Itarumã/degraded land[2]	75.0 t.day^{-1}
RNEST	797.0	18.6	Itarumã/no restriction[1]	150.1 t.day^{-1}
RNEST	855.8	20.0	Itarumã/degraded land[2]	75.0 t.day^{-1}
REVAP	666.0	15.6	Combined supply[3]	300.1 t.day^{-1}
RNEST	707.6	16.5	Combined supply[3]	300.1 t.day^{-1}

[1] Supply site/no restriction on land used;
[2] Supply site/only considering production in degraded pasturelands;
[3] Assuming all ten potential supply sites and no restriction on land use;
[4] Maximum possible production of SAF in each case.

- First, MSP results should be compared to 29 €.GJ^{-1} (1,241 €.t^{-1}), which is the figure presented by de Jong et al. (2015) considering the production based on HEFA pathway, from UCO (used cooking oil), in Europe.
- Le Freuve (2019) stated that production costs based on HEFA-SPK route recently varied between 770 and 1,750 €.t^{-1}.
- Another figure of comparison is the market price of jet fuel. An estimate based on Platts Global Index was 622 €.t^{-1} in May 2018 (see next slide).

Comparing MSPs with jet fuel prices



Source: Platts, Datastream https://www.iata.org/en/publications/economics/fuel-monitor

- Jet fuel market prices is extremely correlated with international oil prices.
- The Platts Global Index indicates that the index price in Latin America is about 12% higher than the global figure. Compared with the world average, in Europe it is about 6% lower and in North America about 8% higher (see Supplementary Material).

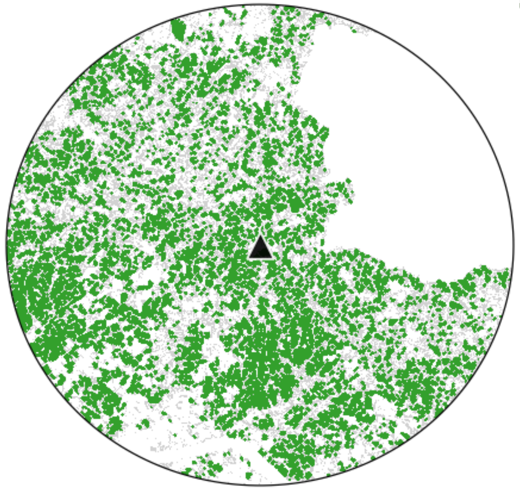
Analysis of the set of results (2)

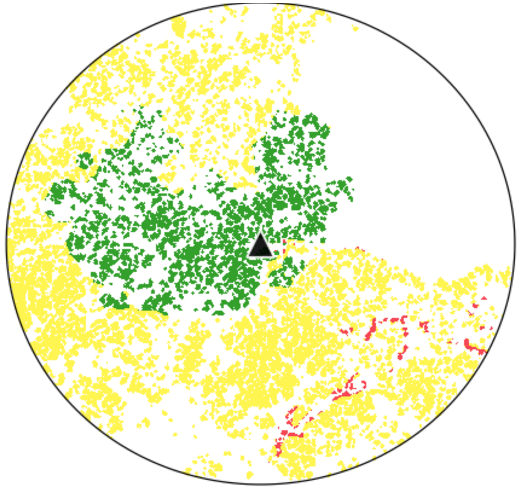
- From an economic point of view, the conclusion is that the production of SAF through the HEFA-SPK pathway, from macauba oil, could be feasible in the future. For this, it would be necessary to identify the best supply sites and to enlarge industrial plant capacities.
- It is not possible to consider commercial production in short to mid-term because there is no well established knowledge regarding macauba cropping.
- Based on the assumptions done, the macauba oil cost represents 36% of the MSP of SAFs in case of the smallest industrial plants (20 $t.day^{-1}$ of SAF) and 58% in case of the largest industrial plants (300 $t.day^{-1}$ of SAF). These results are for the production at REVAP, based on combined supply.
- Due to the still precarious knowledge about commercial production of macauba, there are uncertainties regarding feedstock cost. Assuming a reduction of 20% on costs, due for instance to higher yields, the MSP of the best case would be reduced from 15.6 $€.GJ^{-1}$ to 13.8 $€.GJ^{-1}$, with a clear positive impact on SAF's feasibility.

Analysis of the set of results (3)

- Transporting fresh fruit to the extraction unit has a significant impact on the cost of oil. Here, the hypothesis considered is that all fruit production would be transported to a single point, in the center of a circle with 50 km radius. Based on the results, it seems that the best strategy would be to distribute the extraction in different units, reducing the distances. Each processing unit would have the largest possible capacity, taking into account the technology in use.
- The best solution seems to be combining supply sites, i.e. different production regions should be considered. However, there are sites that have better potential, as it was shown with the results for the production at REVAP and at RNEST that five sites – out of ten considered – could cover about, or even more than, 80% of the required supply in the case of the largest industrial capacity. From an economic point of view, the best sites are not necessarily those that are closer to the industrial unit, as the cost of oil at the industrial site is impacted by the oil yield.

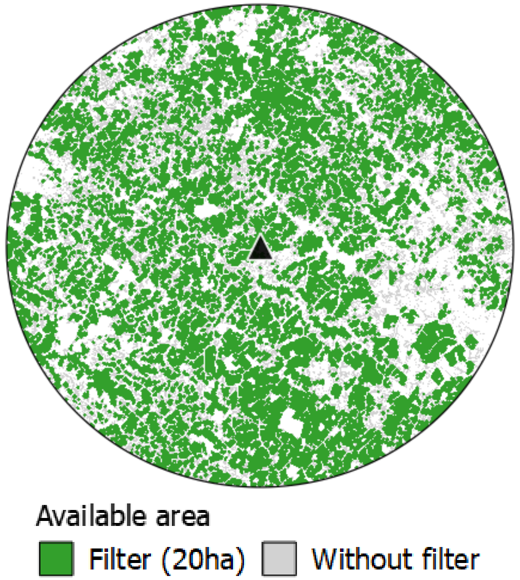
The risks of extensive monoculture (1)

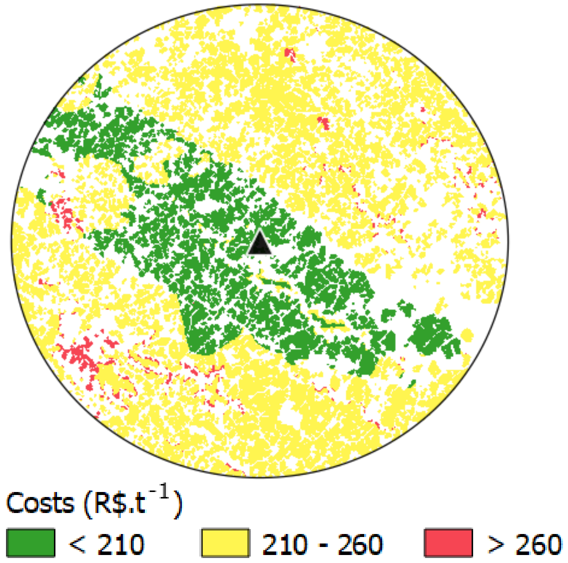




- The high potential in some sites could bring the risk of extensive monoculture, as it could be the case of producing around Itarumã (GO) and Campina Verde (MG) (individually, the two sites with the largest potentials).
- The upper figure shows the areas with potential for macauba production around Campina Verde. After the adopted aggregation procedure (filtering to 20 hectares, minimum), the estimated area for production (green dots) represents 37.6% of the total area inside the circle.
- The lower figure shows the areas classified according to the estimated annual cost of fresh fruit production. Considering the combined supply curve to REVAP, the areas covered with macauba around Campina Verde would be 29% of the total areas around the municipality (almost 229 thousand hectares). It is clear the risk of high concentration.

The risks of extensive monoculture (2)





- The same analysis was done for Itarumã (GO).
- The upper figure shows the areas with potential for macauba production around the municipality. After the aggregation procedure (filtering to at least 20 hectares), the estimated area for production (green dots) represents almost 60% of the total area inside the circle.
- The lower figure shows the areas classified according to the estimated annual cost of fresh fruit production. Considering the combined supply curve to REVAP, the areas covered with macauba around Itarumã would be 28.3% of the total areas around the municipality (more than 222 thousand hectares).
- Potentially, producers can be criticized for practicing extensive monocultures, and this is an aspect to be taken into account.

Eligibility under CORSIA

- Eligible fuels in the context of CORSIA include Sustainable Aviation Fuels (SAF) (produced from biomass or residues) and Lower Carbon Aviation Fuels (LCAF) (from fossil energy sources). In both cases the production must be certified according sustainability. For SAF, in the CORSIA pilot phase (2021-2024) only two principles must be accomplished (see Supplementary Material): 1) SAF should contribute with lower carbon emissions on a life cycle basis, and 2) should not be made from biomass obtained from land with high carbon stocks.
- Here, the accomplishment of Principle 2 is assured by the fact that the production of macauba would occur displacing pasturelands, in areas that were not converted after January 2008.
- Regarding Principle 1, there is no Default Life Cycle Emissions Values for the HEFA route based on macauba. In this sense, the potential SAF producer would have to assess the carbon footprint of its own production, using the methodology approved. For better results, it would be appropriate to minimize the use of fertilizers, the transport of fruits and oil, and the impacts on the stock of soil organic carbon (e.g. producing on recovered degraded pastures).

Other sustainability aspects

- In the assessment presented here the possible negative impacts on biodiversity would be minimized, since sensitive ecosystems and preserved areas were defined as areas of exclusion.
- In addition, it is supposed that macauba would be produced without irrigation. This would avoid negative impacts on water resources.
- Related to negative socioeconomic impacts, risks would be minimized as indigenous reserves, afro-descendant settlements and municipalities with reported violations of land use and water use rights were also considered sensitive areas.

Conclusions

- The reported case study shows that the production of SAF from macaw oil could be feasible in Brazil in mid- to long-term. For the best cases from an economic point of view, the estimated MSP (for the n^{th} plant) show feasibility vis-à-vis current fossil jet-fuel prices. Feasibility depends on some factors, such as oil yield, reduction of transportation distances and on taking advantage of the scale effects in the industrial side.
- The cost of transport represents about 10% of the CIF cost of macauba oil at REVAP, and about 20% when oil is delivered at RNEST, and this is a clear indication that the sites of cultivation areas and extraction points should be focus of special attention.
- In the same sense, the location of the industrial plant must be defined according to strategic aspects, related to the opportunities for using domestically or exporting the final product. Producing at REVAP is the best alternative for consuming SAF in airplanes that departure from the largest international airport in Brazil (Cumbica).
- Due to the relatively small SAF production, as assessed here, it would be convenient to consider the combination of feedstocks, an alternative that could reduce risks.

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Development of Database Management System (DBMS) for Sustainable Aviation Biofuel in Brazil

Case study: HEFA pathway / macaw palm

Supplementary Material

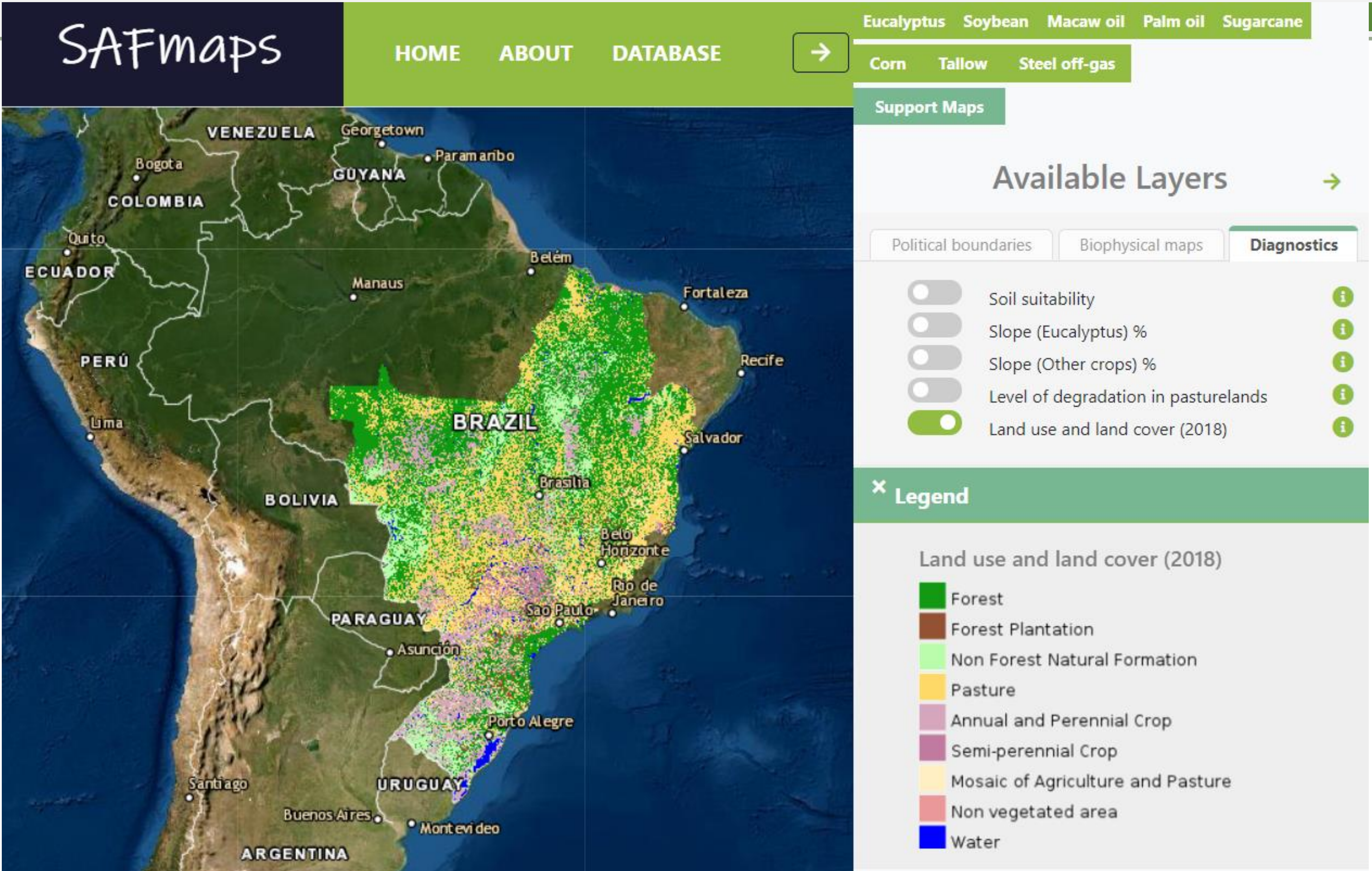
SAFmaps

UNICAMP

List of Contents

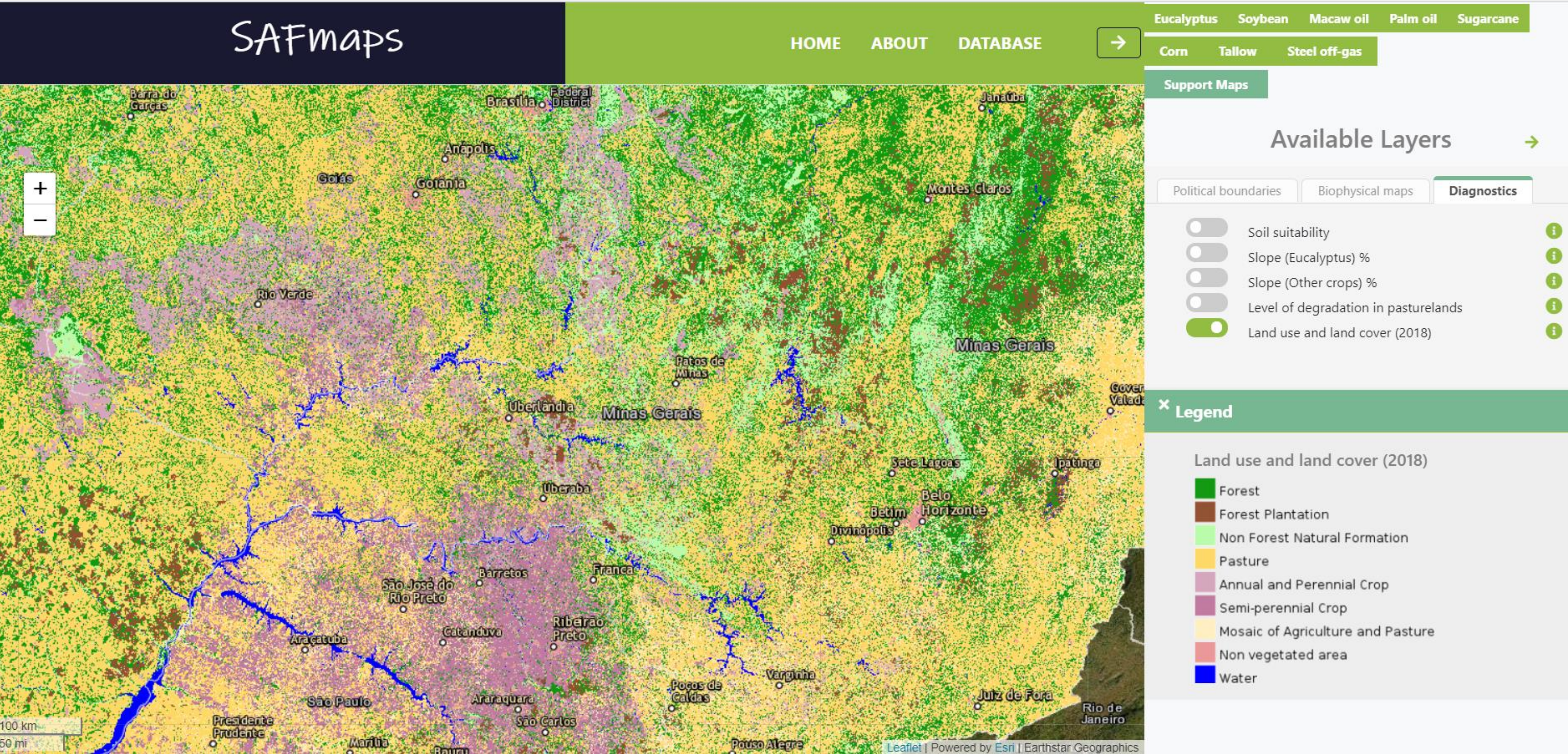
- Land use and land cover;
- Sensitive areas;
- Reported violations to land use and water use rights;
- Macaw suitability;
- About degraded pasturelands;
- Jet fuel prices;
- About CORSIA and eligible fuels;
- Agricultural costs;
- Industrial costs.

Land use and land cover in 2018

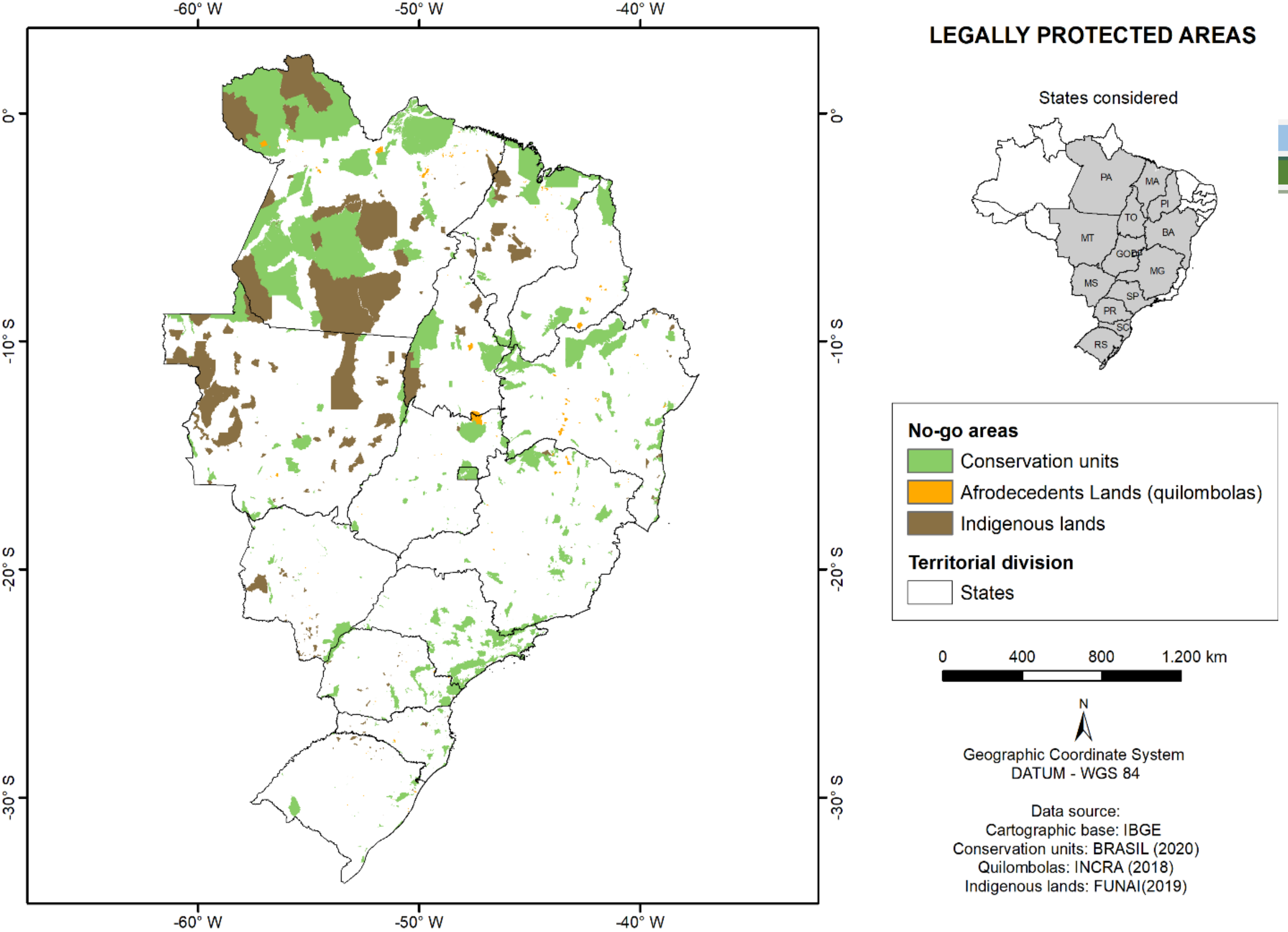


- Figure shows the land use & land cover map available at the platform database and used in this study.
- Information of land use and land cover available at the database corresponds to 2018. The source is Mapbiomas.
- The next slide shows a partial zoom-in image for Southeast (São Paulo and Minas Gerais) and Centre (Goiás) regions.

Land use and land cover in 2018 – detailed image for Minas Gerais and Goiás

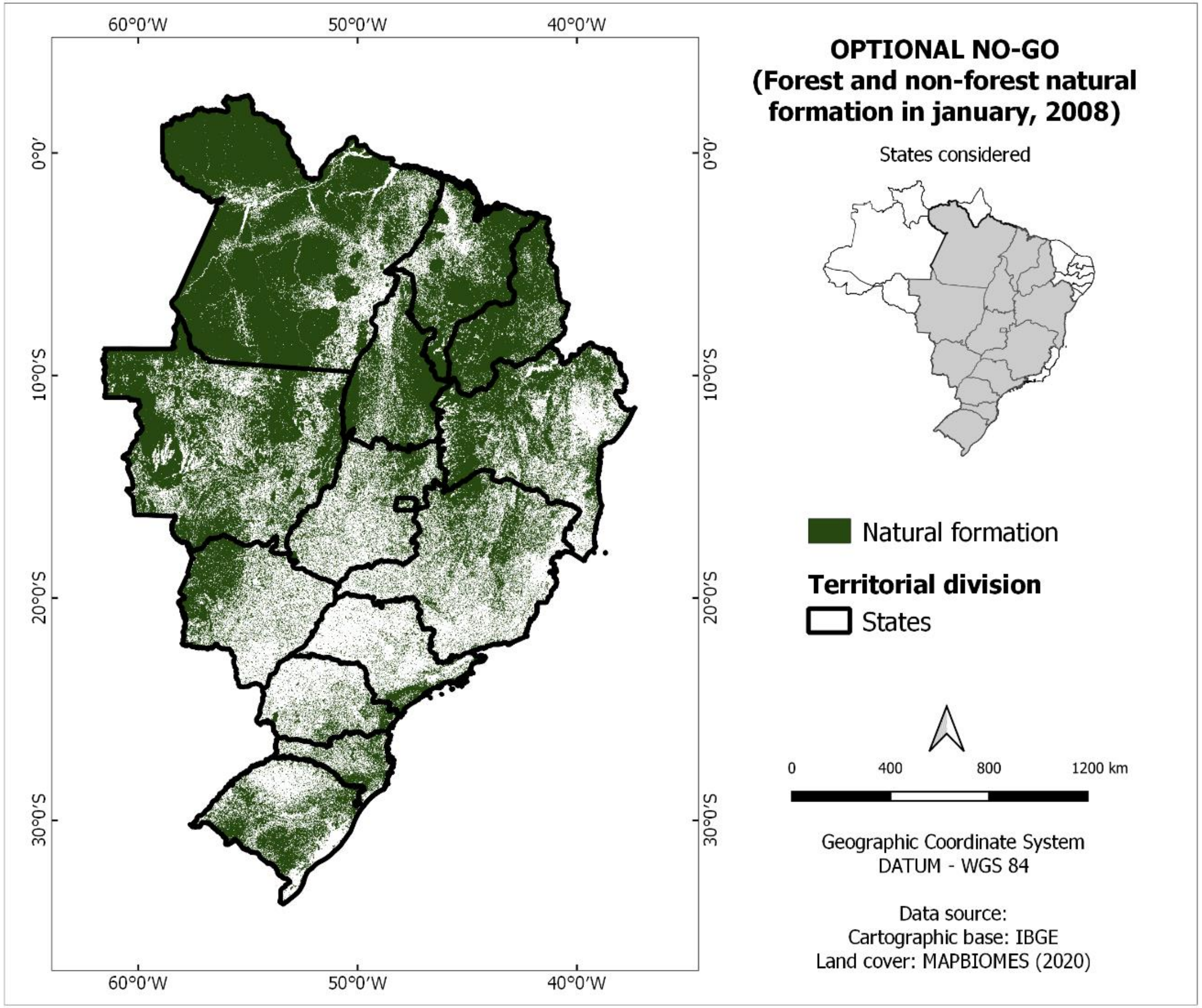


Sensitive areas (1)



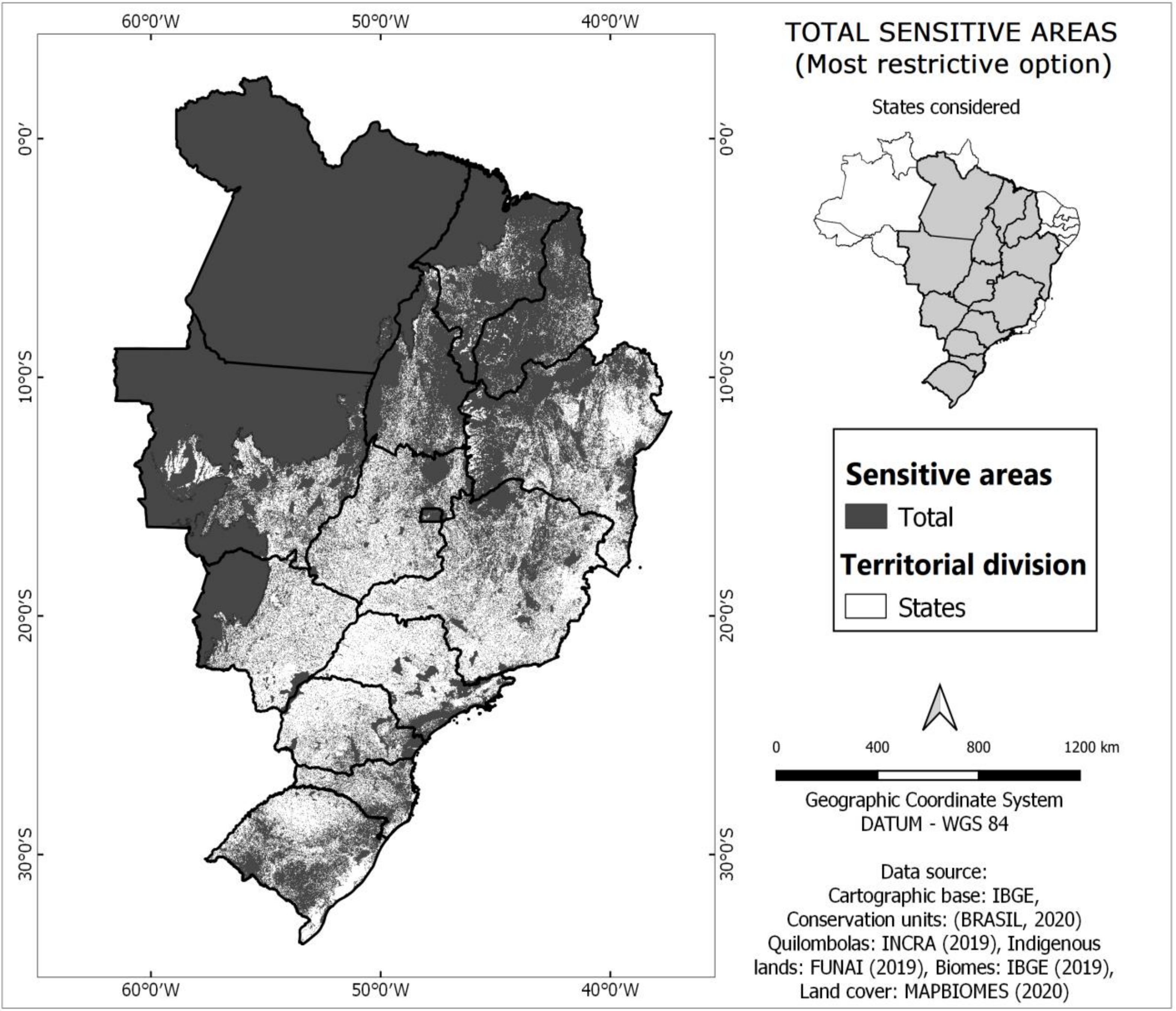
- Feedstock production cannot occur in legally protected areas.
- Legally protected areas include conservation units (for environmental reasons), the land that belongs to Afro-descendants (i.e. quilombola areas, or Afro-Brazilian settlements) and reserves of indigenous peoples.

Sensitive areas (2)

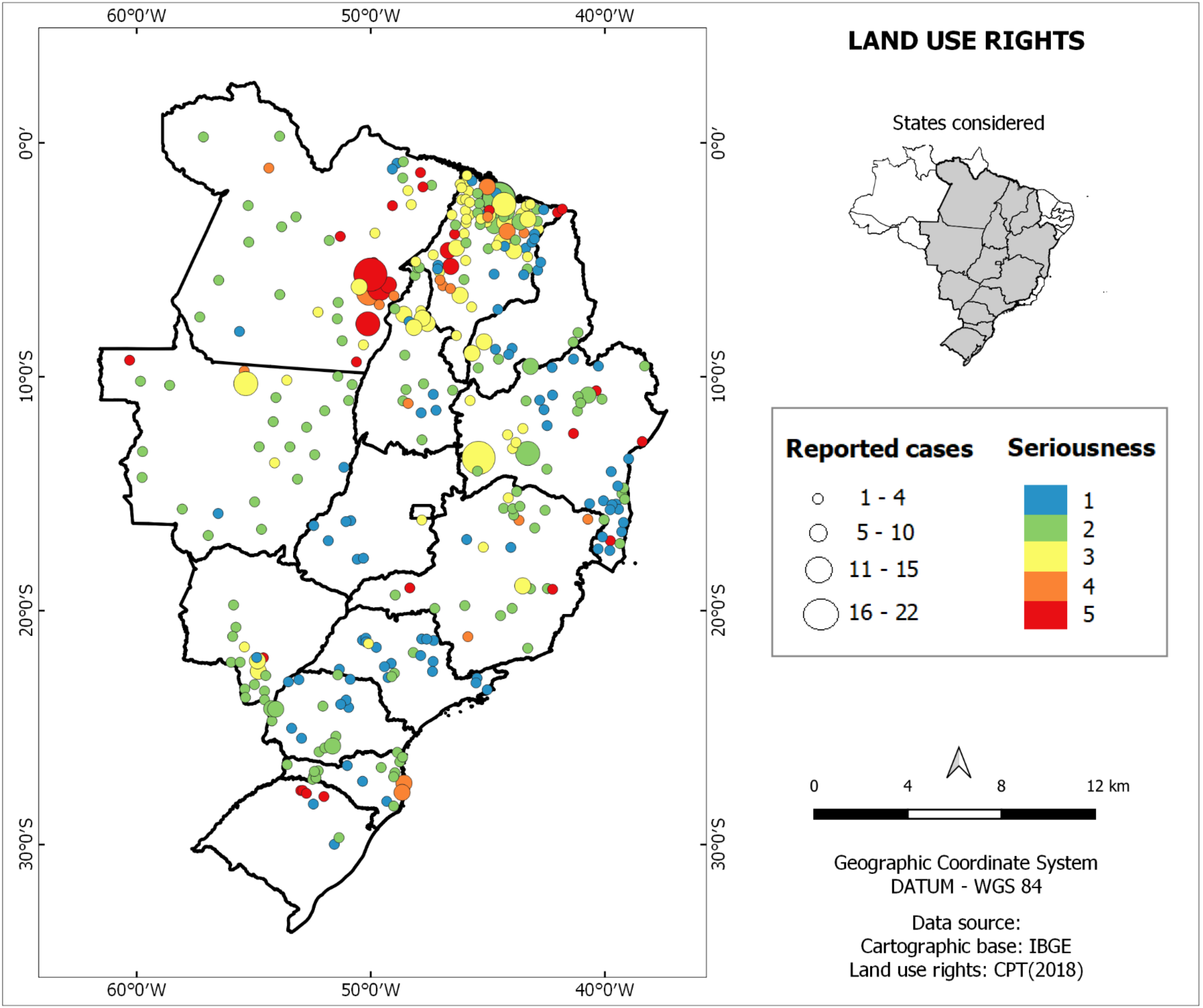


- According to CORSIA, SAF cannot be made from feedstocks obtained in certain areas (for example, primary forests, wetlands, etc.) where land was converted after January 1, 2008 (see information about CORSIA).
- In this sense, a map of land uses and land cover by the end of 2007 was used to define - conservatively - areas that should not be used for this purpose.
- The figure shows the areas with natural vegetation in January 2008. Thus, and conservatively, all areas with natural vegetation at that time were excluded.

Sensitive areas (3)



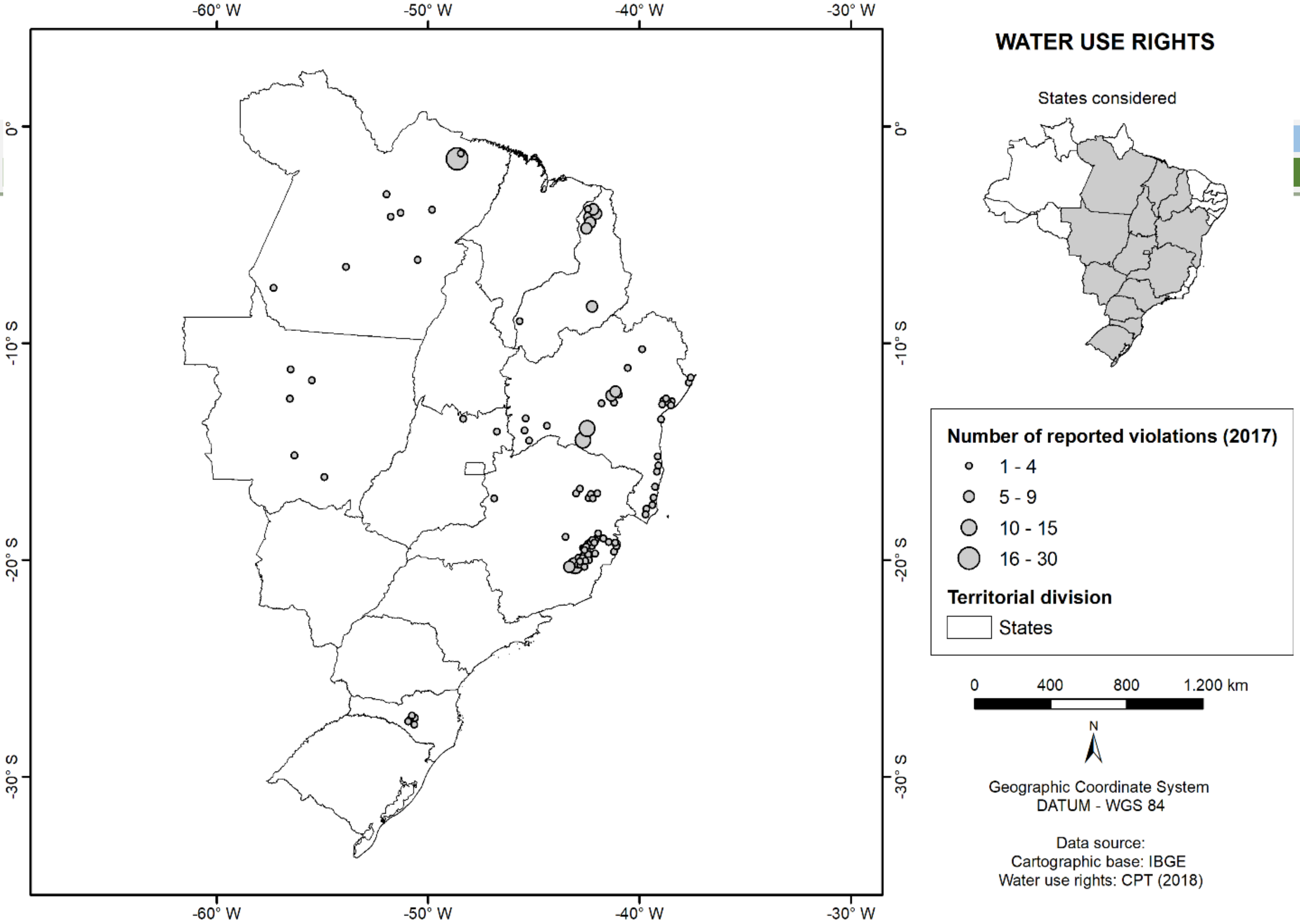
- The figure combines the previous map with areas of the biomes Amazon Forest and Pantanal, which are biodiversity hot-spots.
- In this project, this is the most restrictive option.
- Both maps include, as unusable areas for feedstock production, the lands classified as national parks, areas protected by environmental reasons, indigenous and quilombola areas, etc.



Land use rights

- CPT – Comissão Pastoral da Terra – is an organization linked to the Catholic Church (https://www.cptnacional.org.br/).
- CPT compiles information of reported violations to land use and water use rights.
- The figure shows the locations of reported violations to land use, in the 2016-2018 period.
- Seriousness vary from 1 (e.g. threats) to 5 (e.g. murders); the metric was defined by the authors of this case study. Reported cases is the number of registers in CPT database (in each municipality).

Water use rights



- The number of reported violations to water use rights in 2017 is presented in the figure.
- The cases are related to threats, reduced access to water bodies, pollution, destruction of socio-cultural heritage, illegal procedures, etc.
- Both for land and water use, the reported violations are related to different economic activities (not just to agriculture).

Procedure for defining macaw suitability (1)

- The procedure was defined based on the parameters listed in the table (next slide), whose values correspond to the municipalities in which there is a natural occurrence of macauba, according to information available in the literature (e.g. Castro et al. 2017; Reis et al. 2017; Vilela et al. 2014).
- Values from 45 municipalities (listed below) were used to characterize suitable areas. These municipalities were considered because they have the most reliable information. Values from other 39 municipalities were used to define a broader range, and thus the parameters of suitable and marginal areas were defined. By difference, municipalities were considered suitable and marginal from the suitability point of view. Those who are outside the range were considered inadequate for macauba production. Suitability requires simultaneous matching of all criteria (i.e. rainfall, air temperature, altitude, etc.).
- Minas Gerais: Arapuá, Brasília de Minas, Campos Altos, Carmo do Paranaíba, Coração de Jesus, Córrego Danta, Dores do Indaiá, Ewback da Câmara, Florestal, Ibiá, João Pinheiro, Juiz de Fora, Lagoa Formosa, Lagoa Santa, Lavras, Lima Duarte, Luz, Matutina, Mirabela, Montes Claros, Olaria, Patos de Minas, São Gotardo, São João del Rei, Serra da Saudade.
- Goiás: Cabeceiras, Cachoeira Dourada, Edéia, Faina, Formosa, Formoso, Goiânia, Goiás, Inacionlândia, Palminópolis, Pontalina, Posse, São João da Paraúna, Vila Boa
- Ceará: Crato, Porteiras; Mato Grosso: Campinápolis; Paraíba: Pilões; Pernambuco: Ipojuca.

Procedure for defining macaw suitability (2)

- Table below shows the parameters and the range of values used to classify municipalities as suitable or marginal for cropping macauba in commercial basis.

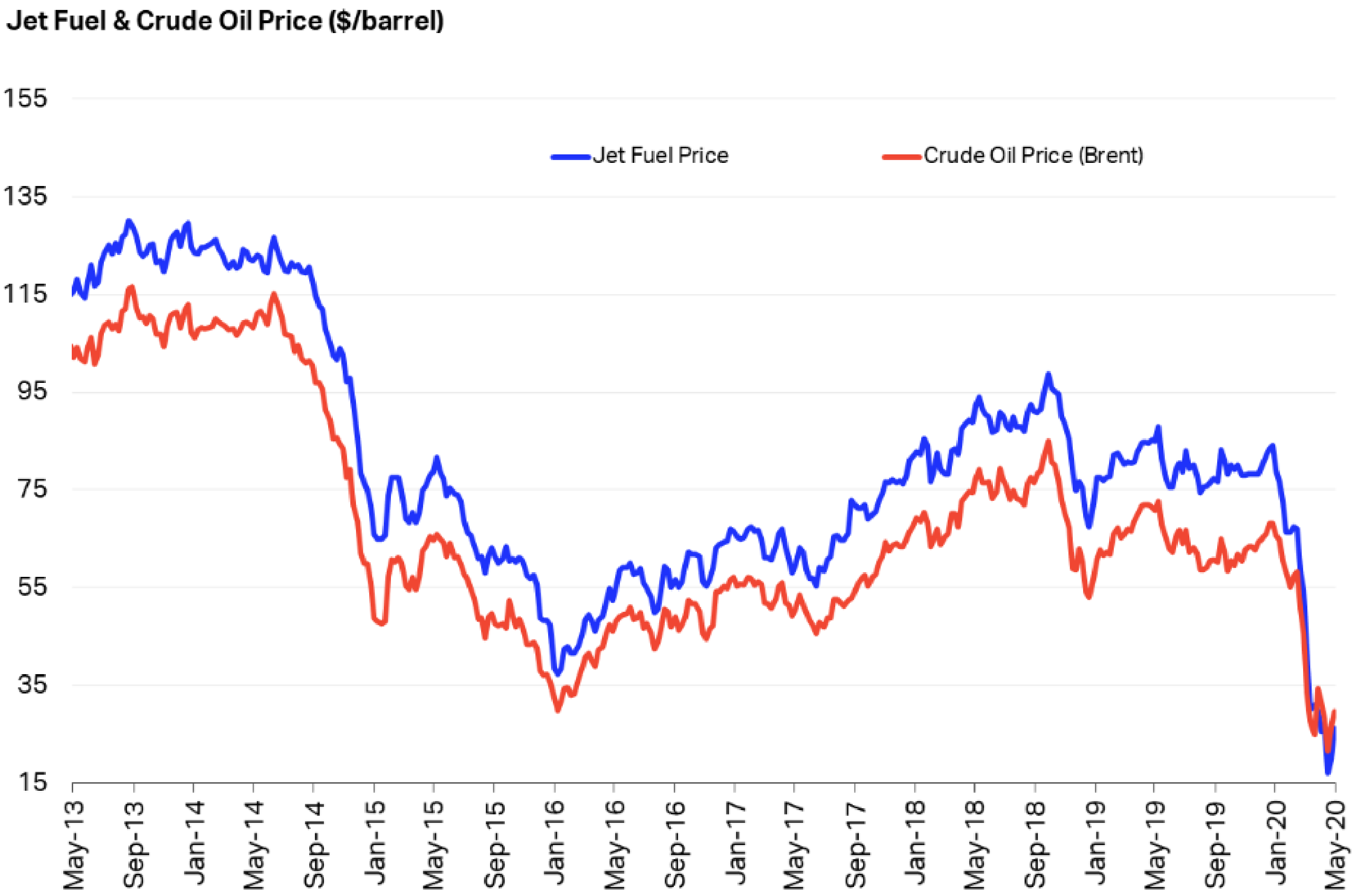
Parameter	Suitable	Unit	Suitable + marginal	Unit
Annual rainfall	Between 874 & 2,052	mm	Between 826 & 2381	mm
Annual hydric deficit	Between 19 & 409	mm	Between 1.8 & 695	mm
# of months of hydric deficit	Between 4 & 8		Between 2 & 8	
IDP (Index of rainfall distribution)	< 0.083		< 0.1041	
T_minimum (annual average)	Between 13.6 & 23.5	°C	Between 12.8 & 29.7	°C
T_average (annual)	Between 17.3 & 25.6	°C	Between 16.6 & 27.8	°C
Altitude	Between 62 & 1,069	m	Between 24 & 1,204	m
Frost risk	< 5.6	%	< 8.9	%

About degraded pasturelands

- The concept of pasture degradation used in the Atlas of Brazilian Pastures (pastagem.org/atlas) (LAPIG, 2018) is based on the definition by Dias Filho (2005; 2014). Degradation is classified as agronomic and biological. The agronomic component corresponds to dirty pastures or with those regeneration of native vegetation, while the biological component is due to the loss of soil fertility and existence of exposed soil.
- The classification of pastures in degradation levels is obtained from the stratification of a vegetative vigor index (normalized NDVI). The classification is based on the literature on remote sensing (e.g. Pereira et al., 2018).
- The pasture quality index is obtained from a median NDVI normalized image for a given year. The resulting values vary between 0 and 1. Classification is as follows: non-degraded area (> 0.6), slightly degraded (0.5-0.6), moderately degraded (0.4-0.5) and severely degraded (< 0.4).
- Images for two of the ten areas here considered for production of macauba are presented in the following slide. Lima Duarte (MG) is the municipality with the lower level of degradation (62% of the pasturelands were classified as non-degraded in 2018), while Figueirópolis (TO) is the one with more degraded pasturelands in the same year (7% non-degraded and 60% severely degraded).

Degraded pasturelands: Lima Duarte (left side) and Figueirópolis (right side)

Jet fuel prices: historical data and worldwide variations



Source: Platts, Datastream

https://www.iata.org/en/publications/economics/fuel-monitor/

- Figure reinforces the common understand that jet fuel prices are strongly correlated to international oil prices.
- Table below shows, as an illustration, the jet fuel average prices in different regions, in May 15, 2020.

Region	US$.barrel^{-1}	US$.t^{-1}
Global average	30.38	239.84
Asia & Oceania	29.47	232.84
Europe & CIS	28.49	224.50
Middle East	25.72	202.93
Africa	25.72	202.93
North America	32.75	258.73
Latin America	34.13	269.63

CORSIA and eligible fuels

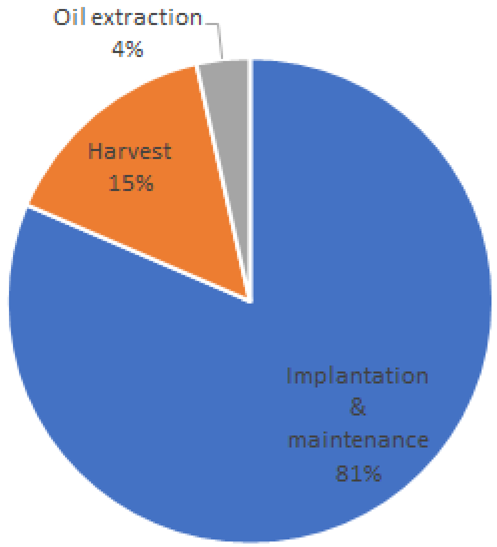
- CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) is a global market-based measure scheme adopted by ICAO Assembly, in 2016, aiming to address the increase of GHG emissions from international aviation. ICAO is the International Civil Aviation Organization.
- An aeroplane operator can reduce its offsetting requirements by the use of CORSIA Eligible Fuels (CEFs), which shall come from fuel producers that are certified.
- In the CORSIA pilot phase, the two principles (and their criteria) that must be met by SAF producers are presented in the table.

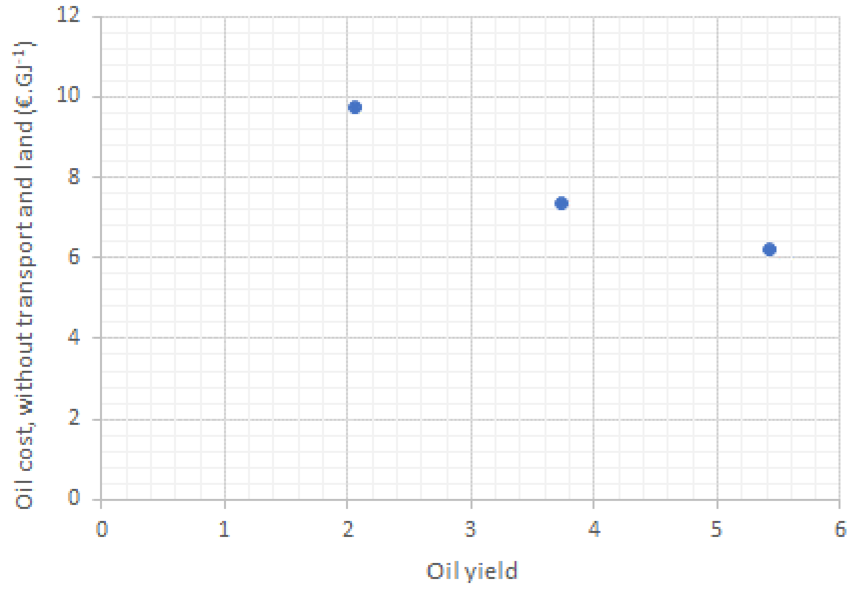
Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2. Carbon stock	Principle: CORSIA eligible fuel should not be made from biomass obtained from land with high carbon stock.	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.

Source: CORSIA (2019)

Agricultural costs

- Agricultural costs were estimated based on information presented by Chagas (2018) and the results were compared with estimates by Pimentel et al. (2017). These costs include (1) implementation and maintenance and (2) harvest, and are impacted by fruits yield and oil content.
- The shares of land opportunity cost and transportation of fruits to the extraction point vary case by case. In the adopted procedure, the calculation was done for each pixel.
- Upper figure shows the cost structure for the case of higher oil yield. Lower figure shows how oil cost varies at the extraction point as function of the oil content, does not taken into account the shares due to land and fruits transportation.
- Here, land prices (for land used as pastures) were taken from the database available at the platform, which was built from different sources of information.





Industrial costs

- Here, the main reference is de Jong et al. (2015), since it is based on a comprehensive review of performance factors and costs for different pathways.
- The process that was taken as reference by the authors is the one developed by Nestè. It was assumed that bio-jet fuel is one of the hydrocarbons that can be produced; the production shares are presented in the table below. The revenue for each product was considered in estimating the MSP of SAF.
- In the base case 0.83 tonne of hydrocarbons could be produced from one tonne of oil.
- In the reference case, the production of bio-jet fuels would be equal to 300 tonnes of bio-jet per day, operating all over the year with a 90% capacity factor.
- Based on the reference, the adjusted total cost investment would be 662.1 million € (2018).
- For estimating the MSP in each case, a spreadsheet was developed and validated against the results presented by de Jong et al. (2015).

Economic hypotheses used by de Jong et al. (2015) for estimating the MSP of bio-jet fuels, and used in this report

Parameter	Value	Unit
Plant lifetime	25	Year
Depreciation period (straight linear method)	10	Year
Debt-to-equity ratio	80:20	
Interest rate on debt	8%	
Rate of principal payments	15	Year
Discount rate	10%	
Corporate tax rate	22%	
Annual capacity factor	90%	
Year	TCI – total cost investment – schedule	Plant availability
-1	30% of fixed capital	0%
0	50% of fixed capital	0%
1	20% of fixed capital	30%
2		70%
3		100%

Hydrocarbons produced	Corrected producing share (%)
Jet-fuel	14.5
Diesel oil	76.9
Naphtha	2.0
LPG	1.8
Propane	4.7